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Effects of Biomass Ashes on Plant Nutrition in Tropical and Temperate Regions

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Abstract

The drastic rise of prices for commercial fertilizers is one of the main obstacles to increase the productivity in crop production, mainly in poor countries. The search for alternatives therefore becomes very important. The reutilization of residues from bionergy processes for plant nutrition is an important concern to save fertilizers and to implement nutrient cycling in agriculture. For this study ashes derived from bioenergy production were investigated. The effect of sugar cane ash (SCA) on lettuce and cucumber was investigated in Cuba and the effects of ashes from wood (WA), poultry litter (PLA), and rape meal (RMA) on ryegrass and oil radish were investigated in Germany. Special attention was given to phosphorus (P) availability. Positive yield effects and an increased plant P uptake were found when ashes were applied (mainly SCA and RMA). Investigation regarding the effect of PLA on soil P pools showed that the ash application may also result in an increase of readily available P contents in soil. Furthermore, an increased plant uptake of potassium was found. The results indicate that ashes derived from the energetic use of biomass may provide a suitable source for plant nutrition.

Keywords: poultry litter ash, wood ash, sugar cane ash, phosphorus, nutrient recycling

1 Introduction

Due to the drastic rise of prices for commercial fertilizers, the search for alternative fertilizer resources becomes increasingly important. The reutilization of residues from bionergy processes for plant nutrition is an important factor to save fertilizers and to realize nutrient cycling in agriculture. The ashes remaining from combustion of biomass are the oldest man-produced mineral fertilizers in the world. They contain nearly all nutrients except of nitrogen (N) and can help to improve plant nutrition (Bhattacharya and Chattopadhyay, 2002). Regarding phosphorus (P), the fertilizer effect of biomass ashes and the solubility of P in ashes are evaluated differently. Positive results were found, among others, by Nkana *et al.* (1998) for wood ash and Codling *et al.* (2002)

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for poultry litter ash. Mozaffari *et al.* (2002) found an increase of extractable soil P after application of alfalfa stem ash. In contrast, a negative effect of wood ash on the plant available P was found by Clarholm (1994). Besides being a source of nutrients itself, the application of biomass ashes may influence the form and availability of P by changing chemical parameters of the soil, mainly the pH (Muse and Mitchel, 1995). The fertilizer effect of ashes also depends on soil type, soil characteristics, and cultivated crops (Nkana *et al.*, 1998; Mozaffari *et al.*, 2002; Eichler-Löbermann *et al.*, 2008).

The urban agriculture in Cuba in so called "Organopónicos" started due to a high necessity for food production during the "*special period*". Currently it is the main source of vegetable production based on a substrate with high content of organic matter and nutrients. Since the application of highly soluble mineral fertilizers is prohibited by law in these cultivation systems (Koont, 2008), the use of biomass ashes can be an alternative for fertilization and nutrients recycling.

The objective of this study was to investigate the fertilizer effect of biomass ashes in different cropping systems in Cuba and Germany. Main emphasize was given to P.

2 Materials and Methods

2.1 Experiments in Cuba

The experiments with cucumber (*Cucumis sativus* L.) and lettuce (*Lactuca sativa* L.) were conducted under field conditions at the Organopónico "18 plantas" in Bayamo from December 2007 to March 2008. The substrate used in these plots was a mixture of soil and compost according to Minagri (1981). At onset of the experiment, the K content of the substrate was 130 mg/kg and the P content 72 mg/kg (Oniani method). The pH ($CaCl_2$) of the substrate was 6.56. The ash used in this study was derived from the combustion of sugar cane residues, and had a P content of 1.3 %.

In order to investigate the effect of sugar cane ash (SCA) on cucumber, 3 different treatments with 4 replications were established in a randomised block design. Each plot had 8 m^2. (Table 1). One control without ash was established as well a treatment with 6 t ash per ha. In the third treatment, 6 t ash were given to the previous crop (lettuce) to investigate the residual ash effect on cucumber. 90 days after sowing the cucumber plants were harvest from 1 m^2 subplots and dry mass determined after drying at 60 °C to constant weight. Additionally, length and diameter of fruits were measured on 5 plants.

In the lettuce experiment, 2 different treatments (with 6 T/ha and without ash) were investigated with 5 replications in a randomized block design (Table 1). Lettuce plants were harvested from 1 m^2 subplots 45 days after sowing and dry mass determined after drying at 60 °C to constant weight. Furthermore, 4 plants from each plot were taken to investigate the height of the plants and the leaf size.

During the vegetation time cucumber and lettuce plants were irrigated. The P content in plant shoot tissue (no fruits were analyzed) was measured after dry ashing using the vanadate-molybdate method (Page *et al.*, 1982).

Table 1: Treatments of the Cuban field experiments with sugar cane ash (1.3 % P)

Cucumber experiment	*Lettuce experiment*
Control - without nutrient supply	Control - without nutrient supply
SCA – sugar cane ash, 6 t/ha	SCA – sugar cane ash, 6 t/ha
SCA-R – residual effect of sugar cane ash (given at 6 t/ha to the previous crop)	

2.2 Experiment in Germany

In order to investigate the effect of 3 different biomass ashes on plant P nutrition a pot experiment was carried out. The soil used was taken from a long-term field experiment from a control plot on which no P fertilizer has been applied since 8 years. The soil texture was loamy sand. Following the FAO nomenclature, the soil is classified as Haplic Luvisol. The double-lactate soluble P content (P_{DL}) of 39 mg/kg soil indicates a severe P deficiency according to the German soil P classification (Anonymus, 2004). The double-lactate soluble soil K and Mg contents (113 and 117 mg/kg, respectively) indicate optimal supply.

Mitscherlich-pots were filled with 6 kg sieved and air-dried soil. Before sowing, each pot received a solution containing 1.4 g NH_4NO_3. Six different treatments were established with 4 replications each (Table 2). In order to separate the P and K effect of ashes, a treatment with KCl but without any P, and a treatment with triple superphosphate (TSP) but without any K was established beside the control and 3 ash treatments. Due to the differences in ash nutrient content (*agua regia* extract), the amount of nutrients given with the ashes varied between the treatments (Table 2). Two crops, oil radish (*Raphanus sativus* L.) and ryegrass (*Lolium westerwoldicum* L.) were grown in an open-air greenhouse. Distilled water was given according to plant requirement. Plants were harvested about 8 weeks after germination when they reached their maximum of biomass weight. Ryegrass was cut two times within the growing period.

Table 2: Treatments of German pot experiment and the amount of nutrients given (mg/pot)

Treatment	*Short name*	*Nutrients per pot*			
		N	P	K	Mg
control	Control	490	–	–	–
potassium (1 g KCl)	KCl	490	–	520	–
phosphorus (1 g TSP)	TSP	490	208	–	–
wood ash (8 g)	WA	490	16	32	48
poultry litter ash (8 g)	PLA	490	160	120	128
rape meal ash (8 g)	RMA	490	728	656	712

DM yield was determined after drying the harvested biomass in an oven at 60°C to constant weight. Total P content in the plant tissue was determined after dry-ashing using the vanadate-molybdate method (Page et al. 1982). Ca, K and Mg were measured photometrically. Soil samples were taken from each pot after harvest, air dried and sieved down to a particle fraction <2 mm. Water extractable P (P_W) was determined according to van der Paauw (1971). P concentration in this extract was determined by the phosphomolybdate blue method applied to flow injection analysis. Double lactate extractable P, K, and Mg, as well as the pH ($CaCl_2$) were determined as described by Blume *et al.* (2000).

2.3 Statistical analyses

The data obtained were subjected to the analysis of variance. The means were compared by the Duncan multiple range test.

3 Results

3.1 Experiments with sugar cane ash in Cuba

For both tested crops a positive yield effect of SCA application was found. For cucumber, the direct fertilization with SCA had a better effect on yields than the residual effect of this ash (Tables 3, 4, 5). However, the residual effect was also found to increase the yield in comparison to the control. The ash application also affected the P uptake of cucumber plants. It was found to be highest in the SCA treatment, followed by the residual SCA treatment.

In lettuce, an increased number of leaves and positive effects on plant height and yield were found in the SCA compared to the control treatment. P uptake was found to be significantly higher in the ash treatment compared to controls (9.16 g/m^2 vs. 2.88 g/m^2, $p = 0.000$).

Table 3: Effect of application of sugar cane ash (SCA) on length and diameter of fruits (cm), yields of fruits (kg/m^2) and P uptake of shoots (g/m^2) of cucumber under field conditions.

	Control	*SCA*	*Residual SCA effect*
Lenght of fruits	20.33 ^{a}	29.21 ^{c}	23.41 ^{b}
Diameter of fruits	5.62 ^{a}	7.87 ^{c}	6.21 ^{b}
Yield of fruits	2.10 ^{a}	3.14 ^{c}	2.70 ^{b}
P uptake (shoot)	5.66 ^{a}	13.8 ^{c}	8.64 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan).

Table 4: Effect of application of sugar cane ash (SCA) on number of leafs, plant height and leaf size (cm^2) of lettuce under field conditions

Treatment	*Number of leafs**				
	20 Dec	*27 Dec*	*3 Jan*	*10 Jan*	*17 Jan*
Control	4.40	7.67	11.8	13.4	16.2
SCA	5.55	8.42	12.4	14.0	18.9
p	0.000***	0.002**	0.082	0,044*	0,000***

	*Plant height**			*Leaf size**
	3 Jan	10 Jan	17 Jan	
Control	3.59	7.27	18.7	342
SCA	4.22	8.00	21.4	340
p	0.002**	0,046*	0.000***	0.918

20 samples per treatment (ANOVA, Duncan 0.05).

Table 5: Effect of application of sugar cane ash (SCA) on yield (kg/m^2), P content (mg/kg DM) and P uptake (g/m^2) of lettuce under field conditions

Treatment	*yield*	P *content*	P *uptake*
control	1.65 ^{a}	1800 ^{a}	2.88 ^{a}
SCA	2.35 ^{b}	3900 ^{b}	9.16 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan).

3.2 Experiment with ashes from wood, poultry litter and rape meal in Germany

In tendency, the highest oil radish and ryegrass yields were obtained when rape meal ash (RMA) was applied (Table 6 and 7), although yield differences were not significant. However, for the first ryegrass cut a significant positive effect was found in the RMA treatment in comparison to the control (DM yield RMA: 10.35 g, control: 8.85 g, $p < 0.05$). The P uptake of both crops increased significantly when TSP, PLA, or RMA were supplied. The highest values were found in the RMA treatment, which was even higher than in the TSP treatment. No effects were found for WA on plant P uptake. The K uptake increased mostly when RMA or KCl were applied.

For treatment PLA and the control treatment, soil tests were carried out. Ash application significantly increased the readily available soil P pools (P_W and P_{DL}) (Table 8). The P_{DL} nearly doubled when ash was applied. For oil radish slightly lower soil P contents were found than for ryegrass, probably due to higher P uptakes of oil radish. Due to the ash supply the average soil pH increased from about 5.7 to 6.6.

Table 6: Yield (DM, g/pot) and nutrient uptake (mg/pot) for ryegrass in the German pot experiment

Treatment	*yield 1*	*yield 2*	*yield total*	*Nutrient uptake total*				
				P	Na	K	Ca	Mg
control	8.85 ^{a}	3.50 ^{b}	12.3	54.9 ^{ab}	21.6 ^{c}	585 ^{a}	133 ^{c}	47.0 ^{b}
KCl	9.17 ^{a}	3.62 ^{b}	12.8	51.7 ^{a}	10.1 ^{a}	795 ^{b}	123 ^{bc}	41.4 ^{a}
TSP	8.92 ^{a}	3.47 ^{b}	12.4	67.2 ^{c}	23.5 ^{cd}	586 ^{a}	119 ^{b}	46.9 ^{b}
WA	9.25 ^{a}	3.55 ^{b}	12.8	56.2 ^{ab}	23.7 ^{cd}	606 ^{a}	129 ^{bc}	45.9 ^{b}
PLA	9.55 ^{ab}	2.72 ^{a}	12.3	62.6 ^{bc}	24.7 ^{d}	621 ^{a}	128 ^{bc}	40.9 ^{a}
RMA	10.77 ^{b}	2.73 ^{a}	13.5	90.6 ^{d}	16.7 ^{b}	785 ^{b}	99 ^{a}	45.6 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)
Yield 1, 2 = dry matter yield of the first and second cut
TSP = TripleSuper-P, WA = wood ash, PLA = poultry litter ash, RMA = Rape meal ash

Table 7: Yield (g/pot) and nutrient uptake (mg/pot) for oil radish in the German pot experiment,

Treatment	*yield FM*	*yield DM*	*Nutrient uptake total*				
			P	Na	K	Ca	Mg
control	219 ^{a}	15.5	73.3 ^{ab}	43.1 ^{b}	560 ^{a}	446 ^{a}	52.9
KCl	238 ^{b}	15.6	70.3 ^{a}	35.4 ^{a}	780 ^{c}	422 ^{a}	50.2
TSP	218 ^{a}	14.8	95.2 ^{c}	47.5 ^{c}	558 ^{a}	465 ^{a}	48.4
WA	216 ^{a}	15.5	76.8 ^{ab}	51.0 ^{d}	581 ^{ab}	471 ^{a}	52.4
PLA	226 ^{ab}	16.6	84.9 ^{bc}	64.8 ^{e}	620 ^{b}	534 ^{b}	49.3
RMA	238 ^{b}	16.3	116.0 ^{d}	77.0 ^{f}	782 ^{c}	415 ^{a}	53.6

different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)
Yield FM = yield of fresh matter, yield DM = yield of dry matter
TSP = TripleSuper-P, WA = wood ash, PLA = poultry litter ash, RMA = Rape meal ash

Table 8: Effect of poultry litter ash (PLA) on soil ph and P content (water soluble (P_W), double-lactate soluble (P_{DL}), mg/kg) in the German pot experiment.

Crop	*Treatment*	*pH*	P_W	P_{DL}
rygrass	control	5.8 ^{a}	2.9 ^{a}	38 ^{a}
	PLA	6.5 ^{b}	4.9 ^{b}	74 ^{b}
oil radish	control	5.7 ^{a}	2.4 ^{a}	33 ^{a}
	PLA	6.6 ^{b}	3.8 ^{b}	56 ^{b}

Different letters indicate significant differences between treatments, $p < 0.05$ (Duncan)

4 Discussion

A high nutrient effectiveness of biomass ashes was observed in the German, as well as in the Cuban experiments under different experimental design and climatic conditions. Generally, the ashes with higher nutrient contents seemed to have the better effects. Thus, in the German experiment best results were found for the RMA treatment, and the lowest effects were found for WA application.

Since ashes contain various nutrient elements, it is difficult to identify the fertilizer effect of a single element. However, main effects in the German experiment can be explained by P and K supply with the different ashes, as it became visible when compared to TSP and KCl treatments. Mg supply seemed do have lower impact on yields in this experiment. The plants Mg uptake was not higher in the ash treatment than in the control. Furthermore, probably the $\mathrm{K{:}Mg}$ antagonisms affected the Mg uptake, which was lowest in the RMA and KCl treatment (these treatments had the highest K uptake). Additionally, a high K uptake went together with low Na and Ca uptakes. Generally, Mg, Ca and K as a rule act as antagonists among each other in nutrient uptake (Järvan, 2004).

The comparatively low yield and nutrient uptakes in the WA treatment showed, that in our experiment the ash effect was mainly related to the nutrient supply and not (or only to a small extend) to the pH effect. In other studies good results were found with ashes derived from woody biomass. These results are often related to pH effect, which may increase the availability of nutrients in soil. Krejsl and Scanlon (1996) found increased dry matter of oat when wood ash was applied. Positive liming effects with wood ash were also found for wheat by Etiegni *et al.* (1991) and Huang *et al.* (1992), as well as for alfalfa and barley by Meyers and Kopecky (1998). Patterson *et al.* (2004a) found a positive effect of wood ash application on oil content of canola, but found that the ash used may also result in an enrichment of undesired elements like Zn and Cd in the rape seed oil. After wood ash application on an acid soil Muse and Mitchel (1995) found an increased Mehlich-1 extractable P, K, and Mg soil content and a yield increase of dallisgrass-fescue herbage.

The high P uptake as well as the increase of soil P contents may be due to a relatively high solubility of P in SCA, GMA and PLA. However, other studies demonstrated only a low to moderate solubility of P in ashes (Erich and Ohno, 1992; Clarholm, 1994). Codling (2006) found 82 % of the total P in poultry litter ash bound in the $\mathrm{H_2SO_4-P}$ fraction, which is only inadequately plant available. In own studies with different biomass ashes from burnt agricultural products, usually more than 90 % of P were soluble in citric acid (Eichler-Löbermann *et al.*, 2008). In general, higher P availability can be expected from agricultural biomass than from wooden biomass ashes (Obernberger, 1997). A fly ash from gasification of alfalfa stems showed a relatively high P availability with 63 % of the total P being soluble in ammonium citrate (Mozaffari *et al.*, 2000), whereas in wood ashes the plant available P content was between 0.33 % and 20 % (Clarholm, 1994; Patterson *et al.*, 2004b).

Beside these effects on chemical soil parameters, the ashes may also influence the physical soil parameters positively. In an experiment with coal fly ash and biogas slurry Garg *et al.* (2005) found a reduced bulk density, an increased saturated hydraulic conductivity and moisture retention capacity in soils.

The fertility of the so called organopónicos, as a special form of Cuban urban agriculture, usually is found to be high. This is mainly due to a high content of organic matter in the soils of up to 40 %. However, due to the year-round crop cultivation there are high nutrient outputs. Thus, according to the soil classification, the levels of P and K at the beginning of the experiment were suboptimal. Usually the nutrient balance is warranted by the application of compost products and bio-fertilizers (Terry *et al.*, 2002). The results show that the application of ashes from biomass combustion may have a positive effect in this production system. Since the pH at the beginning of the experiment was in optimum with 6.5, and a further increase due to the liming effect of the ash would not have any advantage, we expect the main ash effect to be due to the nutrient application. The amount of P applied with the ash was quiet high with 80 kg per ha. This may explain the high P uptake of cucumber and lettuce after SCA application.

5 Conclusions

The results underlined the fertilizer potential of biomass ashes under tropical and temperate conditions. Provided that the ashes are not loaded with harmful substances, the usage of those ashes is an important method for nutrient recycling in agriculture – even for food crop cultivation – and saving of nutrient resources.

References

Anonymus; Düngung, Hinweise und Richtwerte für die landwirtschaftliche Praxis; Ministerium f. Landwirtschaft, Forsten und Fischerei MV; 2004.

Bhattacharya, S. S. and Chattopadhyay, G. N.; Increasing bioavailability of phosphorus from fly ash through Vermicomposting; *J Environm Qual*; 31:2116–2119; 2002.

Blume, H. P., Deller, B., Leschber, R., Paetz, A., Schmidt, S. and Wilke, B. M.; *Handbuch der Bodenuntersuchung. Terminologie, Verfahrensvorschriften und Datenblätter. Physikalische, chemische und biologische Untersuchungsverfahren. Gesetzliche Regelwerke*; Wiley-VCH: Weinheim; 2000.

Clarholm, M.; Granulated wood ash and a “N-free” fertilizer to a forest soil. Effects on P availability; *Forest Ecol Managem*; 66:1209–1036; 1994.

Codling, E. E.; Laboratory characterization of extractable phosphorus in poultry litter and poultry litter ash; *Soil Sci*; 11:858–864; 2006.

Codling, E. E., Chaney, R. L. and Scherwell, J.; Poultry litter ash as a potential phosphorus source for agricultural crops; *J Environm Qual*; 31:954–961; 2002.

Eichler-Löbermann, B., Schiemenz, K., Makadi, M., Vago, I. and Köppen, D.; Nutrient cycling by using residues of bioenergy production - II Effects of biomass ashes on plant and soil parameters; *Cereal Res Comm*; 36:1259–1262; 2008.

Erich, S. and Ohno, T.; Phosphorus availability to corn from wood ash amended soils; *Water Air Soil Poll*; 64:475–485; 1992.

Etiegni, L., Campbell, A. G. and Mahler, R. L.; Evaluation of wood ash disposal on agricultural land. I. Potential as a soil additive and liming agent; *Commun. Soil Sci Plant Anal*; 22:243–256; 1991.

Garg, R. N., Pathak, H., Das, D. K. and Tomar, R. K.; Use of fly ash and biogas slurry for improving wheat yield and physical properties of soil; *Environm Monitoring Assessm*; 107:1–9; 2005.

Huang, H., Campbell, A. G., Folk, R. and Mahler, R. L.; Wood ash as a soil additive and liming agent for wheat: Field studies; *Commun Soil Sci Plant Anal*; 23(1&2):25–33; 1992.

Järvan, M.; Available plant nutrients in growth substrate depending on various lime materials used for neutralizing of peat; *Agron Res*; 2:29–37; 2004.

Koont, S.; A Cuban Success Story: Urban Agriculture; *Rev Radical Pol Economics*; 40:285–291; 2008.

Krejsl, J. A. and Scanlon, T. M.; Evaluation of beneficial use of wood fired boiler ash on oat and bean growth; *J Environ Qual*; 25:950–954; 1996.

Meyers, N. L. and Kopecky, M. J.; Industrial wood ash as a soil amendment for crop production; *Tappi Journal*; 81:123–130; 1998.

Minagri; *Suelos, Análisis químicos, Reglas generales. Norma Ramal 279*; Dirección de Normalización, Metrología y Control de la Calidad, La Habana, Ministerio de la Agricultura, Cuba; 1981.

Mozaffari, M., Rosen, C. J., Russelle, M. P. and Nater, E. A.; Chemical characterization of ash from gasification of alfalfa stems: Implications for ash management; *J Environm Qual*; 29:936–972; 2000.

Mozaffari, M., Russelle, M. P., Rosen, C. J. and Nater, E. A.; Nutrient supply and neutralizing value of alfalfa stem gasification ash; *Soil Sci Soc Am J*; 66:171–178; 2002.

Muse, J. K. and Mitchel, C. C.; Paper mill boiler ash and lime by-products as soil liming materials; *Agron J*; 87:432–438; 1995.

Nkana, J. C. V., Demeyer, A. and Verloo, M. G.; Availability of nutrients in wood ash amended tropical acid soils; *Environm Techn*; 19:1213–1221; 1998.

Obernberger, I.; Aschen aus Biomassefeuerungen. Zusammensetzung und Verwertung; *VDI-Berichte Düsseldorf*; 1319:199–222; 1997.

van der Paauw, F.; An effective water extraction method for the determination of plant-available soil phosphorus; *Plant Soil*; 34:467–481; 1971.

Page, A. L., Miller, R. H. and Keeney, D. R.; *Methods of soil analysis. Chemical and microbiological properties (2nd edn.)*; Madison, WI, USA; 1982.

Patterson, S. J., Acharya, S. N., Bertschi, A. B. and Thomas, J. E.; Application of wood ash to acidic boralf soils and its effect on oilseed quality of canola; *Agron J*; 96:1344–1348; 2004a.

Patterson, S. J., Acharya, S. N., Thomas, J. E., Bertschi, A. B. and Rothwell, R. L.; Barley Biomass and Grain Yield and Canola Seed Yield Response to Land Application of Wood Ash; *Agron. J.*; 96:971–977; 2004b.

Terry, E., Terán, Z., Martínez-Viera, R. and Pino, M. d. l. A.; Biofertilizantes, una alternativa promisoria para la producción hortícola en orgánoponicos; *Cultivos Tropicales*; 23(3):43–46; 2002.