Chapter 2
Phosphorus Fertilizing Effects of Biomass Ashes

Katja Schiemenz, Jürgen Kern, Hans-Marten Paulsen, Silvia Bachmann, and Bettina Eichler-Löbermann

Abstract The reutilization of biomass ashes in agriculture is important to create nutrient cycles. In field and pot experiments we investigated the fertilizing effects of different biomass ashes (rape meal ash, straw ash, and cereal ash) for eight different crops on a loamy sand and a sandy loam. Special emphasis was given to phosphorus (P). The ashes showed large differences in their elemental composition. The highest P contents (10.5%) were measured in the cereal ash, and lowest in straw ash (1% P). The solubility of P in water was low; however, about 80% of P was soluble in citric acid. Generally, the P fertilizing effect of ashes was comparable to that of highly soluble P fertilizers such as triple superphosphate. The ash supply resulted in an increase of P uptake of cultivated crops as well as in increased soil P pools (total P, water-soluble P, double-lactate-soluble P, oxalate-soluble P) and P saturation. The ash effects depended also on the cultivated crop. Good results were found in combination with phacelia, buckwheat, and maize. Provided that biomass ashes are low in heavy metals and other toxic substances, the ashes can be applied in agriculture as a valuable fertilizer.

2.1 Introduction

Renewable energy sources are important for reducing the EU's dependence on fossil fuels and cutting greenhouse gas emissions and other pollutants. "Biomass is one of the most important resources for reaching our renewable energy targets.

K. Schiemenz, S. Bachmann, and B. Eichler-Löbermann (✉)
Faculty of Agricultural and Environmental Sciences, University of Rostock, J.-von-Liebig-Weg 6, 18059 Rostock, Germany
e-mail: bettina.eichler@uni-rostock.de

J. Kern
Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V., Max-Eyth-Allee 100, 14469 Potsdam, Germany

H.-M. Paulsen
Institute of Organic Farming vTI, Trenthorst 32, 23847 Trenthorst, Germany

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It already contributes more than half of renewable energy consumption in the European Union" said Günther Oettinger, Europe's energy commissioner in February 2010, when the European Commission adopted a report on sustainability requirements for the use of solid biomass and biogas in electricity, heating, and cooling (European Commission 2010).

In the context of increasing bioenergy production, the recycling of the residues in agriculture can contribute to realize nutrient cycles and reduce the necessity of commercial fertilizer application (see Chap. 3, Haraldsen et al. 2011; Chap. 7, Bougnom et al. 2011). This has special importance for phosphorus (P), since the P resources are strongly limited worldwide. Ashes from combustion of biomass are the oldest mineral fertilizer. Biomass ashes are nearly free of nitrogen but contain P and other nutrients needed for plant nutrition (Sander and Andrén 1997; Vance and Mitchell 2000; Patterson et al. 2004; Uckert 2004). Furthermore, biomass ashes can also be used as liming agents (Muse and Mitchell 1995; Mandre 2006), and can stimulate microbial activities in the soil (Demeyer et al. 2001; see Chap. 1, Knapp and Insam 2011).

The nutrient compositions of ashes are affected by different factors. Particularly, the kind of biomass combusted influences the quality and the nutrient values of ashes. Besides the raw material used, the combustion process itself affects the chemical composition of the ashes. The P concentration in biomass ashes may range from less than 1% up to 10% (Table 2.1).

Positive effects of biomass ashes on crop yields were found in different studies. Among others, Krejsl and Scanlon (1996) found wood ashes to increase oat and bean yields. Phongpan and Mosier (2003) found positive effects of rice hull ash on rice yield, Ikpe and Powell (2002) reported positive impacts of millet ash on millet yields, and Haraldsen et al. (2011, see Chap. 3) found particularly positive combination effects with meat and bone meal residues on barley.

Nutrient uptake efficiency and mobilization mechanisms of crops are important for high utilization of applied P (Schilling et al. 1998; Neumann 2007), and the utilization of P in ashes also depends on the cultivated crop. However, research findings concerning interactions between biomass ashes and crop species are rarely available.

In our studies we investigated three different crop biomass ashes and eight crop species within field and pot experiments. The objectives of our work were to evaluate the P fertilizing effect of biomass ashes on different soils, and to investigate possible interactions between the effects of ashes and cultivated crops.

Table 2.1 P contents in biomass ashes

Type of ash	P content (%)
Bagasse ash (Jamil et al. 2004)	0.01
Alfalfa stem ash (Mozaffari et al. 2002)	0.90
Horticulture ashes (Zhang et al. 2002)	0.04–1.00
Wood ashes (Erich and Ohno 1992; Saarsalmi et al. 2001; Hytönen 2003)	0.90–1.70
Wheat straw ash (Hytönen 2003)	1.30
Rape straw ash (Hytönen 2003)	2.10
Poultry litter ash (Yusiharni 2001; Codling et al. 2002)	5.00
Cereal ash (Eichler et al. 2008b)	10.4

2.2 Material and Methods

2.2.1 Treatments and Experimental Design

Two field experiments were conducted on different soil types at the agricultural experimental stations of the University of Rostock (loamy sand) and at the Institute of Organic Farming in Trenthorst (sandy loam). The same soil types were also used for the pot experiments in Rostock; in 2007 the experiments were established on loamy sand and in 2008 they were established on sandy loam (Table 2.2).

The rape meal ash (RMA) was produced at the University of Rostock in a fluidized bed combustion at 860°C. The rye straw ash (SA) was produced via grate firing at 750°C and was supplied by the Leibniz Institute for Agricultural Engineering in Potsdam-Bornim (Germany). The rye cereal ash (CA) was manufactured at the Agricultural Technical School of Tulln (Austria) also via grate firing at 650–850°C. The fertilization treatments in the field and pot experiments were established in respect of the nutrient contents of the ashes (Table 2.3). Heavy metal contents are given in Table 2.4.

Table 2.2 Soil characteristics at the beginning of the field and pot experiments

	Type of soil	pH	OM	Pw	Pdl	Pox	PSC	DPS
		$CaCl_2$	(%)	(mg kg^{-1})		(mmol kg^{-1})		(%)
Field experiments								
Rostock (0–30 cm)	Loamy sand	5.70	1.9	16.9	67.2	15.9	29.3	54.0
Trenthorst (0–30 cm)	Sandy loam	6.36	3.5	23.8	81.9	17.3	42.1	41.1
Pot experiments								
2007	Loamy sand	5.69	2.4	10.6	38.9	11.9	30.5	39.1
2008	Sandy loam	6.17	3.6	7.6	39.3	9.9	37.4	26.6

OM organic dry matter, *Pw* water-soluble P, *Pdl* double-lactate-soluble P, *Pox* oxalate-soluble P, *PSC* P sorption capacity, *DPS* degree of P saturation

Table 2.3 Treatments, nutrient concentrations of the ashes and nutrient supply, field and pot experiments

Fertilization treatments	Nutrient concentrations (%)			Field experiments				Pot experiments (6 kg soil per pot)			
				Fertilizer application rates (kg ha^{-1}) for 2 years	Nutrient supply ($kg\ ha^{-1}$) for 2 years			Fertilizer application rates (g pot^{-1})	Nutrient supply (g pot^{-1})		
	P	K	Mg		P	K	Mg		P	K	Mg
CON	–	–	–	–	–	–	–	–	–	–	–
Phosphorus (TSP)	20.2	–	–	–	–	–	–	1.00	0.20	–	–
RMA	8.0	7.3	5.5	650	51.7	47.5	35.4	2.50	0.20	0.18	0.14
SA	1.0	5.3	1.0	850	8.8	44.8	8.2	9.80	0.10	0.52	0.10
CA	10.5	10.8	3.3	500	52.4	54.2	16.7	1.90	0.20	0.21	0.06
Potassium (KCl)	–	52.4	–	–	–	–	–	1.00	–	0.52	–

CON control; *TSP* triple superphosphate; *RMA* rape meal ash; *SA* straw ash; *CA* cereal ash

Table 2.4 Heavy metal contents (mg kg^{-1}) and pH values of the biomass ashes

Biomass ash	pH	Cd	Cr	Cu	Hg	Ni	Pb	Zn
RMA	12.6	0.5	227.9	77.1	0.02	273.6	11.9	348.9
SA	11.1	0.1	4.7	24.5	0.02	3.7	<1.5	80.9
CA	12.9	1.3	13.7	170.9	0.04	13.1	2.6	750.5

RMA rape meal ash; *SA* straw ash; *CA* cereal ash

Table 2.5 Cultivated crops in the experiments in 2007 and 2008

Year	Field experiments		Pot experiments	
	Rostock	Trenthorst	Main crops	Catch crops
2007	Summer barley	Summer wheat	Maize, blue lupin, summer barley, oilseed rape	Oil radish, phacelia, Italian ryegrass, buckwheat
2008	Maize	Blue lupin		

In the 2-year field experiments with different crop plants (see Table 2.5) the three ashes were applied once at the beginning of the experiments and incorporated into the top soil. Nitrogen was given in all treatments according to good fertilization practice.

In the pot experiments six different fertilization treatments were established. Besides the ash treatments, other treatments included triple superphosphate (TSP) as a highly soluble P source, potassium chloride (KCl) as a highly soluble potassium source, and a control (CON) without P and potassium. The ashes/fertilizers were applied on the soil surface and mixed into the upper 5 cm of soil. For nitrogen supply, 1.4 g NH_4NO_3 per pot was given. Mitscherlich pots with 6 kg soil each were used for crop cultivation.

Eight different crops were investigated in the pot experiments. Depending on the favourable growing time of cultivated main crops and catch crops, two experiments per year were established (Table 2.5). The main crops were seeded in April and the catch crops were seeded in August. The crop growing period in the pot experiments was about 7–10 weeks until the time of maximum biomass. In field and pot experiments all treatments were replicated four times.

2.2.2 Analyses

Harvested shoots were dried at 60°C, weighed, ground with a plant mill, and stored for further investigations. The P content in plant tissue was measured after dry ashing using the molybdovanadate method (Page et al. 1982). Plant P uptake was calculated by multiplying the P content of the shoots and shoot biomass.

The soil samples were air-dried and sieved (2 mm) before analysis. Soil pH was measured in 0.01 M $CaCl_2$ using a 1:2.5 soil-to-solution ratio. For characterization of soil P pools, different methods were used. The method described by Van der Paauw (1971) was used to determine water-extractable P (Pw) with a soil-to-water ratio of 1:25. The P concentrations in the extracts were measured by the phosphomolybdate blue method via flow-injection analysis. The content of double-lactate-soluble P (Pdl) (photometric method) was quantified according to Blume et al. (2000). By means of the ammonium oxalate method (Schwertmann 1964) the extractable amount of P (Pox) allows the estimation of the amount of inorganic P being adsorbed on amorphous iron and aluminium oxides in the soil. Pox and the oxalate-soluble aluminium and iron contents (Alox, Feox) in soil were extracted and their concentrations were determined by inductively coupled plasma optical emission spectroscopy (ICP-OES; JY 238, Jobin Yvon, France). With use of these data, the P-sorption capacity [PSC (mmol kg^{-1}) = (Alox + Feox)/2] and the degree of P saturation [DPS (%) = Pox/PSC × 100] could be calculated according to Lookman et al. (1995) and Schoumans (2000). Total P was analysed after aqua regia dissolution in a microwave oven (Mars Xpress, CEM, Kamp-Lintfort, Germany) followed by ICP-OES.

Furthermore, the sequential P fractionation method developed by Hedley et al. (1982) was used. Different P fractions of decreasing bioavailability (resin-P, $NaHCO_3$-P, NaOH-P, H_2SO_4-P) were extracted step by step by using stronger extracting agents. The remaining P in the soil sample after the extraction steps is considered as residual P. The residual P content was determined by subtracting the amount of extracted P from the total P content [residual P = total P − (resin-P + $NaHCO_3$-P + NaOH-P + H_2SO_4-P)] as described by Schlichting et al. (2002). Total P was determined by aqua regia digestion in a microwave oven.

2.2.3 Statistics

Soil and plant data corresponding to four spatial replications were subjected to two- and one-factorial analysis of variance (general linear model). The results are reported as main effects and interactions. The means of soil and plant parameters were compared by the Duncan test. Significances were determined at $p \leq 0.05$. Significantly different means were indicated by using different characters. The statistical analysis was carried out using SPSS 15.0.

2.3 Results and Discussion

2.3.1 Effect of Biomass Ashes on P Uptake and Shoot Biomass

In the field experiments positive results of ash supply were found in Rostock on the loamy sand (Table 2.6), but not in Trenthorst on the sandy loam (Table 2.7). In Rostock in 2007 higher barley yields (significant) and higher P uptakes (by trend) were found after SA and RMA application in comparison with the control. For maize in 2008 the best effects were found again after SA supply but also after CA supply (Table 2.6).

Table 2.6 Effect of biomass ashes on yield and P uptake, Rostock field experiment (loamy sand)

Fertilization	Summer barley (grain) 2007		Maize (whole plant) 2008	
	Yield (FM, 14% water) ($dt\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)	Yield (DM) ($dt\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)
	0.039*	0.261 NS	0.012*	0.007**
CON	30.2 a	11.6	162 a	32.2 a
SA	35.3 b	13.0	180 b	39.2 c
RMA	35.5 b	13.1	165 a	33.3 ab
CA	33.6 ab	12.7	179 b	37.0 bc
Mean	33.6	12.6	172	35.4

Different characters indicate significant different means at $p \leq 0.05$ within a column
$*p \leq 0.05$; $**p \leq 0.01$
FM fresh matter, *DM* dry matter, *CON* control, *SA* straw ash, *RMA* rape meal ash, *CA* cereal ash, *NS* not significant

Table 2.7 Effect of biomass ashes on yield and P uptake, Trenthorst field experiment (sandy loam)

Fertilization	Summer wheat (grain) 2007		Blue lupin (grain) 2008	
	Yield (FM, 14 % water) ($dt\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)	Yield (FM, 14% water) ($dt\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)
	0.370 NS	0.418 NS	0.184 NS	0.134 NS
CON	32.6	11.6	37.2	11.0
SA	31.5	11.3	37.0	10.7
RMA	31.1	11.1	33.6	9.8
CA	31.5	11.3	36.9	10.5
Mean	31.7	11.3	36.2	10.5

FM fresh matter, *CON* control, *SA* straw ash, *RMA* rape meal ash, *CA* cereal ash, *NS* not significant at $p \leq 0.05$

The missing effects in the Trenthorst experiment concerning yield and P uptake (Table 2.7) were most probably related to the soil conditions, mainly to the higher pH of this soil (Tables 2.2, 2.10, 2.11). Therefore, the liming effect of biomass ashes did not result in a further advantage regarding the availability of nutrients, like we expected for sandy soils with lower pH. Furthermore, the soil P content in the Trenthorst soil was higher, which may have masked the P fertilizing effects of the ashes.

Owing to the lower soil volume, the fertilizing effects were higher in the pot experiments than in the field experiments. Significant effects were found for both soils in the 2007 and 2008 experiments.

The crop P uptake increased when P was supplied, independently of whether ash or TSP was added. In 2007, maize showed the highest P uptake of all main crops, with a mean value of 91.3 mg pot^{-1}. In comparison with the control, the maize P uptake rose owing to P supply. The highest increasing rates were found for CA (about 34%) and TSP (about 44%) (Table 2.8). These results are in coherence with the biomass yield of maize (data not shown).

In 2008 on sandy loam, barley, which generated the highest biomass, also had the highest P uptake (especially after RMA supply: 94.6 mg pot^{-1}) (Table 2.9).

Table 2.8 Effect of biomass ashes on P uptake of the main crops and the catch crops in the pot experiments in 2007 (loamy sand)

Fertilization	Maize	Blue lupin	Summer barley	Oilseed rape	Oil radish	Phacelia	Italian ryegrass	Buckwheat
	P uptake of the shoots (mg pot^{-1}) (relative values in parentheses)							
	0.000***	0.073 NS	0.000***	0.000***	0.006**	0.038*	0.000***	0.567 NS
CON	75.6 a	25.3	59.1 a	43.8 a	64.2 abc	99.8 a	61.1 b	103.8
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
TSP	109.2 d	32.5	79.3 d	62.4 d	77.5 c	127.2 b	86.1 e	116.3
	(144)	(128)	(134)	(142)	(121)	(127)	(141)	(112)
RMA	99.9 bc	35.8	75.1 cd	60.9 cd	75.0 bc	136.1 b	89.5 e	121.6
	(132)	(142)	(127)	(139)	(117)	(136)	(146)	(117)
SA	91.4 b	27.2	70.1 bc	55.2 bc	54.6 a	135.9 b	70.2 c	111.0
	(121)	(108)	(119)	(126)	(85)	(136)	(115)	(107)
CA	101.0 cd	25.9	61.7 a	49.3 ab	77.0 c	129.5 b	78.6 d	127.7
	(134)	(102)	(104)	(113)	(120)	(130)	(129)	(123)
KCl	70.8 a	27.5	66.1 ab	43.5 a	62.6 ab	116.4 ab	51.8 a	113.1
	(94)	(109)	(112)	(99)	(98)	(117)	(85)	(109)
Mean	91.3	29.0	68.5	52.5	68.5	124.1	72.9	115.6

Different characters indicate significant different means at $p \leq 0.05$ within a column $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

CON control, *TSP* triple superphosphate, *RMA* rape meal ash, *SA* straw ash, *CA* cereal ash

Table 2.9 Effect of biomass ashes on P uptake of main crops and catch crops in the pot experiments in 2008 (sandy loam)

Fertilization	Maize	Blue lupin	Summer barley	Oilseed rape	Oil radish	Phacelia	Italian ryegrass	Buckwheat
	P uptake of the shoots (mg pot^{-1}) (relative values in parentheses)							
	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
CON	44.3 a	53.6 ab	67.1 a	47.2 a	57.2 a	110.9 a	51.5 ab	110.5 bc
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
TSP	69.2 c	61.6 bc	92.7 b	78.4 b	94.1 c	144.4 c	80.4 c	137.1 d
	(156)	(115)	(138)	(166)	(165)	(130)	(156)	(124)
RMA	71.7 cd	64.9 c	94.6 b	73.2 b	89.3 c	150.3 c	73.5 c	120.8 cd
	(162)	(121)	(141)	(155)	(156)	(136)	(143)	(109)
SA	56.7 b	56.3 bc	70.6 a	67.9 b	71.4 b	142.0 c	55.9 b	78.2 a
	(128)	(105)	(105)	(144)	(125)	(128)	(109)	(71)
CA	77.0 d	74.0 d	88.6 b	73.0 b	86.7 c	150.0 c	80.1 c	127.5 cd
	(174)	(138)	(132)	(155)	(152)	(135)	(156)	(115)
KCl	45.4 a	46.4 a	62.7 a	51.9 a	64.6 ab	123.5 b	47.8 a	86.6 ab
	(102)	(87)	(93)	(110)	(113)	(111)	(93)	(78)
Mean	60.7	59.5	79.4	65.2	77.2	136.8	64.9	110.1

Different characters indicate significant different means at $p \leq 0.05$ within a column $***p \leq 0.001$

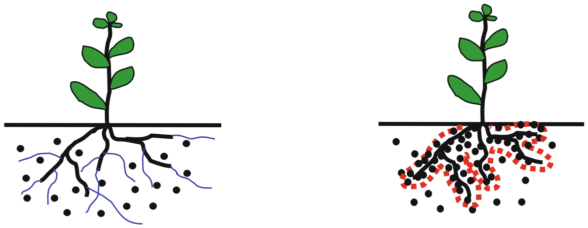
CON control, *TSP* triple superphosphate, *RMA* rape meal ash, *SA* straw ash, *CA* cereal ash

Maize and lupin showed notable positive reactions on CA fertilization, with up to 74% more P uptake than in the control. For the catch crops, the highest P uptakes were found for phacelia and buckwheat in both pot experiments in 2007 and 2008.

Crop-specific P utilizations from the P sources were also relevant. In 2007, usually the highest effects were found for TSP and RMA, whereas the effects of RMA were a little smaller than those of TSP. The opposite was found for lupin and phacelia, with slightly better results due to RMA. In consequence of the lower P concentration, SA application usually resulted in a lower crop P uptake than the other ashes. For oil radish after SA supply, even lower values were found than in the control without P. However, the P uptake of phacelia in the SA treatment was 36% higher than in the control. The SA effect on the P uptake of phacelia was even comparable to the RMA effect (Table 2.8). Differences in P uptake were also found after CA application, with high values for maize and rather low values for barley and lupin.

These effects underline the crop-specific mechanisms (see also Fig. 2.1) which should be considered when planning ash application within the crop rotation. Plant-specific adaptation mechanisms may warrant a sufficient P supply also under conditions of P deficiency in soil. For example, rape may excrete organic acids in the root zone, which is an effective strategy to increase P uptake mainly on soil with higher pH (Hoffland 1992). Buckwheat has been shown to have different P uptake efficiencies depending on soil conditions (Zhu et al. 2002). According to Van Ray and Van Diest (1979), different plant species differ in their behaviour with respect to uptake of cations. Excessive accumulation of cations within the plant can result in net excretion of H^+, and in a lowering of pH values in soil, as was found in our experiments after cultivation of phacelia and buckwheat. Besides such kinds of chemical modifications in the rhizosphere, morphological root adaptations of plants may also help to supply plants with P (Fig. 2.1).

High P uptake of catch crops used as green manure provides a high potential for P supply of succeeding crops, when the decomposing catch crop releases P. According to our results, buckwheat and phacelia, which had high P uptake rates when fertilized with ashes, could be suitable in this sense. Furthermore, a combination of green manure crops and ash application can also provide the soil with organic material, which ashes do not contain.



morphological enhanced spatial availability:

- enhanced root:shoot ratio
- elongation of root hairs
- enhanced formation of fine roots
- enhanced mycorrhizal colonization

physiological enhanced chemical availability:

- changes in rhizosphere chemistry (pH; redox potential)
- release of organic acids and enzymes

Fig. 2.1 Nutrient mobilization due to morphological and physiological mechanisms. (Modified from Neumann and Römheld 2002)

2.3.2 Effect of Biomass Ashes and Cultivated Crops on Soil Characteristics

In the field experiment in Rostock the bioavailable Pw and Pdl contents in soil (0–30 cm) were slightly increased following P supply (Table 2.10). Owing to a high standard deviation, these differences were not significant. The effects of the three ashes were similar. On average, slightly higher P values were measured for the CA treatment.

In Trenthorst the ashes also resulted in higher bioavailable P contents in soil (the differences were significant in spring 2008). Again, the highest increasing effect was found for the CA treatment (Table 2.11).

Like for the plant characteristics, the effects on the soil P pool were also found to be higher in the pot experiments than in the field experiments. Significant increases of high available P contents in the soil due to P application were measured at the end of the pot experiments.

In the pot experiments in 2007 with loamy sand the cultivated crops and interactions between crop and fertilization had also an effect. Cultivation of lupin resulted in the highest P values (Table 2.12). This can be partly explained by the

Table 2.10 Effect of biomass ashes on pH values and contents of water-soluble P and double-lactate-soluble P in the soil (0–30 cm), Rostock field experiment (loamy sand)

Fertilization	At harvest 2007			Spring 2008		At harvest 2008		
	pH	Pw (mg kg^{-1})	Pdl (mg kg^{-1})	Pw (mg kg^{-1})	Pdl (mg kg^{-1})	pH	Pw (mg kg^{-1})	Pdl (mg kg^{-1})
	0.398 NS	0.733 NS	0.701 NS	0.850 NS	0.692 NS	0.599 NS	0.840 NS	0.782 NS
CON	5.60	13.5	61.7	13.6	61.8	6.00	8.8	57.6
SA	5.60	15.3	64.3	14.7	63.7	5.96	9.4	59.8
RMA	5.63	13.9	64.3	14.1	62.9	5.96	9.7	60.0
CA	5.67	14.3	66.4	14.9	65.2	5.98	9.7	61.2
Mean	5.62	14.2	64.2	14.3	63.4	5.98	9.4	59.6

CON control, *SA* straw ash, *RMA* rape meal ash, *CA* cereal ash, *Pw* water-soluble P, *Pdl* double-lactate-soluble P, *NS* not significant at $p \leq 0.05$

Table 2.11 Effect of biomass ashes on pH values and contents of water-soluble P and double-lactate-soluble P in the soil (0–30 cm), Trenthorst field experiment (sandy loam)

Fertilization	At harvest 2007			Spring 2008		At harvest 2008		
	pH	Pw (mg kg^{-1})	Pdl (mg kg^{-1})	Pw (mg kg^{-1})	Pdl (mg kg^{-1})	pH	Pw (mg kg^{-1})	Pdl (mg kg^{-1})
	0.876 NS	0.689 NS	0.295 NS	0.590 NS	0.038*	0.909 NS	0.835 NS	0.236 NS
CON	6.39	21.9	80.7	18.2	80.0 a	6.46	18.6	76.3
SA	6.40	20.9	81.0	19.0	79.1 a	6.47	18.6	75.7
RMA	6.39	22.2	83.7	19.1	80.3 a	6.48	20.0	77.6
CA	6.44	22.7	84.6	20.3	84.6 b	6.49	19.6	80.1
Mean	6.41	21.9	83.8	19.2	81.0	6.47	19.2	77.4

Different characters indicate significant different means at $p \leq 0.05$ within a column $^*p \leq 0.05$
CON control, *SA* straw ash, *RMA* rape meal ash, *CA* cereal ash, *Pw* water-soluble P, *Pdl* double-lactate-soluble P, *NS* not significant

Table 2.12 Effect of biomass ashes and crops on pH values and contents of water-soluble P and double-lactate-soluble P in the soil (0–30 cm), pot experiments in 2007 (loamy sand)

Fertilizer	Maize	Blue lupin	Summer barley	Oilseed rape	Oil radish	Phacelia	Italian ryegrass	
	Buckwheat		pH					
	0.005**	0.036*	0.408 NS	0.336 NS	<0.001***	0.240 NS	0.002**	0.006**
CON	5.49 ab	5.54 ab	5.67	5.71	5.36 b	5.04	5.57 a	5.27 a
TSP	5.43 a	5.51 a	5.69	5.65	5.36 b	5.04	5.59 a	5.19 a
RMA	5.54 ab	5.53 a	5.69	5.67	5.47 bc	5.10	5.71 bc	5.37 a
SA	5.70 c	5.67 b	5.77	5.72	5.63 c	5.06	5.80 c	5.61 b
CA	5.58 bc	5.68 b	5.69	5.77	5.43 b	4.94	5.65 ab	5.33 a
KCl	5.44 ab	5.51 a	5.73	5.65	5.15 a	4.94	5.57 a	5.20 a
Mean	5.53	5.57	5.71	5.70	5.40	5.02	5.65	5.33
	Pw (mg kg^{-1})							
	0.000***	0.018*	0.000***	0.000***	0.000***	0.000***	0.025*	0.000***
CON	7.5 a	10.4 ab	7.8 a	8.0 a	8.7 a	8.1 a	9.6 a	8.0 a
TSP	10.7 bc	15.3 c	11.5 c	11.9 b	12.8 b	11.3 b	12.3 b	15.5 b
RMA	10.8 bc	12.7 abc	10.0 b	12.5 b	12.5 b	11.0 b	10.9 ab	15.7 b
SA	9.5 b	13.5 bc	10.1 b	11.5 b	15.5 c	10.9 b	10.6 ab	14.4 b
CA	11.9 c	11.7 abc	7.5 a	11.1 b	12.7 b	12.3 b	12.2 b	13.9 b
KCl	7.5 a	9.2 a	7.9 a	8.1 a	8.4 a	7.7 a	9.3 a	7.6 a
Mean	9.6	12.1	9.1	10.5	11.8	10.2	10.8	12.5
	Pdl (mg kg^{-1})							
	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
CON	33.0 a	34.7 a	33.3 a	33.8 a	31.7 a	26.4 a	33.7 a	29.5 a
TSP	39.5 b	44.9 b	41.9 b	41.2 b	39.2 b	32.1 bc	40.8 b	43.8 b
RMA	39.3 b	44.7 b	41.2 b	43.5 b	38.6 b	32.1 bc	42.0 b	42.5 b
SA	40.1 b	45.8 b	41.5 b	42.0 b	44.7 c	34.4 cd	42.0 b	45.2 b
CA	42.2 b	48.3 b	34.6 a	43.5 b	40.7 bc	35.5 d	41.2 b	41.5 b
KCl	32.8 a	34.9 a	34.1 a	32.2 a	30.6 a	30.4 b	34.2 a	31.3 a
Mean	37.8	42.2	37.8	39.4	37.6	31.8	39.0	39.0

Different characters indicate significant different means at $p \leq 0.05$ within a column $^{*}p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$

CON control, *TSP* triple superphosphate, *RMA* rape meal ash, *SA* straw ash, *CA* cereal ash, *Pw* water-soluble P, *Pdl* double-lactate-soluble P, *NS* not significant

low P uptake of this species (Table 2.8). Furthermore, in many studies P mobilization effects were found for lupin, albeit mainly for white lupin (Shen et al. 2003; Kania 2005) owing to special root morphology (cluster roots) and root-induced chemical changes in the rhizosphere. According to results of Egle et al. (2003) and Pearse et al. (2007), blue lupin, which was used in the pot experiments, does not generate such “cluster roots”, but can enhance nutrient availability by means of carboxylate excretion into the soil and uptake of cations.

The decrease of the readily available P directly after phacelia harvest is probably only a temporary process. In a long-time field experiment with various catch crops, phacelia cultivation resulted in high levels of bioavailable P in the soil (Eichler-Löbermann et al. 2008a).

In the pot experiments with sandy loam (2008) the Pw and Pdl contents in the soil were also influenced by fertilization. The highest values were found after RMA, CA, and TSP application (Table 2.13).

Remarkably, in the experiments in 2007 and 2008 there were no differences in Pw contents of the soil between the P fertilizing treatments (TSP and ashes), even though commercial TSP fertilizer contains 80–93% water-soluble P (Mullins and Sikora 1995) and the water solubility of P in crop ashes is usually lower than 1% (Eichler-Löbermann et al. 2008b).

The P contents in soil were also related to the crop P uptake, namely high P uptakes usually resulted in P exhaustion in soil and in lower soil P contents. Thus, the relatively low P uptake of oil radish (Table 2.9) was related to rather high Pw and Pdl values (Table 2.13). Phacelia, which had the highest P uptake of all crops, showed comparably lower Pw and Pdl values. In contrast, high soil P contents were

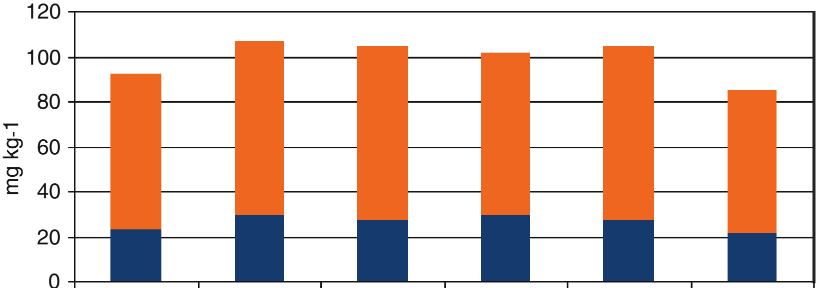
Table 2.13 Effect of biomass ashes and crops on pH values and contents of Pw and Pdl in the soil (0–30 cm), pot experiments in 2008 (sandy loam)

Fertilizer	Maize	Blue lupin	Summer barley	Oilseed rape	Oil radish	Phacelia	Italian ryegrass	Buckwheat
	pH							
	<0.001***	<0.001***	0.006**	<0.001***	<0.001***	<0.001***	<0.001***	0.002**
CON	6.05 b	5.84 a	6.08 a	6.02 ab	5.79 a	5.51 a	6.09 a	5.81 a
TSP	5.98 a	5.79 a	6.06 a	5.98 a	5.83 ab	5.60 ab	6.15 ab	5.75 a
RMA	6.12 c	5.84 a	6.15 ab	6.07 b	5.95 b	5.70 b	6.27 cd	5.77 a
SA	6.20 d	6.02 b	6.26 c	6.18 c	6.15 c	5.83 c	6.41 e	6.03 b
CA	6.09 bc	5.84 a	6.21 bc	6.03 ab	5.93 b	5.63 b	6.23 bc	5.89 ab
KCl	6.09 bc	5.82 a	6.14 ab	6.06 b	5.95 b	5.51 a	6.32 d	6.00 b
Mean	6.09	5.86	6.15	6.06	5.93	5.63	6.24	5.88
	Pw (mg kg^{-1})							
	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
CON	6.1 a	6.5 a	5.9 a	7.3 a	6.6 a	6.5 a	5.7 a	5.7 a
TSP	9.8 bc	11.1 c	10.0 b	9.8 b	11.3 b	10.2 d	10.5 b	11.4 c
RMA	10.4 bc	11.2 c	9.5 b	10.4 b	12.2 b	9.1 c	11.0 b	11.2 c
SA	9.1 b	9.2 b	8.5 b	10.3 b	10.7 b	8.1 b	9.7 b	8.6 b
CA	11.0 d	11.3 c	9.0 b	9.7 b	11.4 b	10.2 d	10.0 b	10.7 bc
KCl	5.9 a	6.8 a	5.8 a	6.5 a	5.5 a	6.0 a	6.3 a	6.3 a
Mean	8.7	9.3	8.1	9.0	9.6	8.3	8.9	9.0
	Pdl (mg kg^{-1})							
	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
CON	34.4 a	34.5 a	33.0 a	34.1 a	28.2 a	26.8 a	32.1 a	28.3 a
TSP	44.1 b	46.0 cd	45.4 d	43.3 b	42.5 b	39.2 c	44.1 b	43.9 b
RMA	44.7 b	43.7 bc	42.4 bc	43.4 b	42.6 b	35.8 b	45.4 b	42.2 b
SA	43.8 b	41.3 b	41.6 b	44.3 b	41.3 b	35.8 b	45.8 b	43.3 b
CA	45.8 b	47.1 d	44.6 cd	44.7 b	46.9 c	39.7 c	44.2 b	45.6 b
KCl	34.9 a	33.2 a	34.3 a	33.2 a	29.3 a	27.8 a	33.8 a	32.8 a
Mean	41.3	41.0	40.2	40.5	38.5	34.2	40.9	39.4

Different characters indicate significant different means at $p \leq 0.05$ within a column

**$p \leq 0.01$; ***$p \leq 0.001$

CON control, *TSP* triple superphosphate, *RMA* rape meal ash, *SA* straw ash, *CA* cereal ash, *Pw* water-soluble P, *Pdl* double-lactate-soluble P



	CON	TSP	RMA	SA	CA	KCl
Pt	504	527	532	516	516	503
🟧NaHCO3-P	69	77	77	72	77	64
🟦Resin-P	23	30	27	30	28	22
sum % of Pt	18.3	20.3	19.7	19.7	20.3	17.0

Fig. 2.2 Average values of resin P and $NaHCO_3$ P in a pot experiment with main crops (maize, blue lupin, summer barley, oilseed rape) and loamy sand in 2007. *Pt* total P, *CON* control, *TSP* triple superphosphate, *RMA* rape meal ash, *SA* straw ash, *CA* cereal ash

found after buckwheat cultivation in the ash and TSP treatments (Table 2.13), despite the high P uptakes (Table 2.9).

The P fractionation method can provide additional information about the pathway of remaining ash P in the soil and helps to predict its presumable availability. In the pot experiments the highest soluble P fractions (resin P and $NaHCO_3P$) were increased by the ashes as well as by TSP, as was shown, for example, for the loamy sand (see Fig. 2.2). The less available P fractions (NaOH P, H_2SO_4 P, and residual P) however, were not affected (data not shown). In comparison with the control, the total P content increased when P was supplied (Fig. 2.2).

2.4 Conclusions

According to our results, a high fertilization effect of biomass ashes can be expected. In the pot experiments and in the field experiment in Rostock, biomass ashes led to raised P uptakes of the crops and increased contents of the more easily available P pools in soil (Pw, Pdl, resin P, $NaHCO_3$ P). Interactions of biomass ashes and cultivated crops had an additional effect on the utilization of P in ashes and should be considered for practical fertilization decisions. Provided that the ashes do not contain harmful substances, the utilization of biomass ashes in crop production is an important method for the recirculation of nutrients in agriculture and may save nutrient resources.

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