The effect of meat and bone meal on phosphorus concentrations in soil and crop plants

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ABSTRACT

A four-year field experiment was conducted in north-eastern Poland. The aim of the study was to determine the direct and residual effects of increasing doses of meat and bone meal (MBM) on the available phosphorus content of soil and the total phosphorus content in crops above ground biomass or grain. Experimental factor I was MBM dose (1.0, 1.5, 2.0 and 2.5 t/ha/year, and 2.0, 3.0, 4.0 and 5.0 t/ha/every second year), and experimental factor II was the year of the study (four consecutive years). The application of increasing MBM doses to slightly acidic soil insignificantly decreased its pH, but it did not change soil classification. The use of MBM as a fertilizer increased the levels of available phosphorus, compared to the treatments with mineral fertilization. The grain of winter triticale and winter wheat and the green matter of maize contained higher concentrations of phosphorus after the MBM application, in comparison to the plants receiving mineral fertilization. Phosphorus uptake by winter wheat and maize plants (dry matter basis) was higher in treatments with MBM (in particular applied every second year) than in treatments with NPK fertilization. Irrespective of the frequency of MBM application, phosphorus uptake by winter rapeseed was considerably lower, compared to the control plants.

Keywords: available P; soil pH; triticale; rape; wheat; maize; uptake; animal meal

Apart from manure, slurry, sludge and other organic wastes (Hanč et al. 2008, Kulhánek et al. 2008), meat and bone meals (MBM) can be a viable alternative to phosphate fertilizers (Valenzuela et al. 2001, Jeng et al. 2006, Svoboda et al. 2010, Chen et al. 2011, Brod et al. 2012, Nogalska et al. 2012). Agricultural utilization of MBM has become an important consideration since a complete ban on the feeding of ruminant-derived protein to ruminants, which was introduced to control bovine spongiform encephalopathy (BSE). Following the Council's decision of 4 December 2000, the ban on the use of processed animal protein in animal feed was extended to non-ruminants (pigs and poultry). As an animal by-product, MBM contains not only substantial amounts of protein but also phosphorus, calcium, microelements and organic compounds. In MBM, phosphorus is present in soluble organic form (meat fraction), which is partly available to plants, and in the form of apatite (bone fraction). The release of phosphorus from apatite requires the presence of H^+ ions (Jeng et al. 2006, Ylivainio et al. 2008).

The utilization of nutrients supplied by animal meals is determined by their chemical composition, degree of grinding, soil pH, method of fertilizer application to soil, plant species and climate conditions. According to Warren et al. (2009), bone meals are a richer source of available phosphorus for crops than phosphates. In addition, MBM has a high calcium content and can be used as a substitute for liming. Fernandes et al. (2010) do not recommend applying high doses of MBM to light and acidic soils which can promote the release of excessive amounts of soluble phosphorus. In a lysimetric experiment, Stępień and Szymczyk (2009) demonstrated that only intensive, annual application of MBM caused a significant increase in nitrogen and phosphorus concentrations in groundwater. Since nitrates and phosphates released during mineralization of MBM are easily leached out, MBM should not be applied in early spring and late fall (Jeng and Vagstadt 2009).

The objective of this study was to determine the direct and residual effects of increasing MBM doses on available phosphorus abundance in soil and phosphorus uptake by plants grown in a four-year crop rotation.

MATERIAL AND METHODS

A field experiment was carried out in 2006–2010 at the Agricultural Experiment Station in Bałdy, owned by the University of Warmia and Mazury in Olsztyn (north-eastern Poland). The two-factorial experiment was performed in a randomized block design with four replications, on soil that was classified as Haplic Cambisol according to the FAO (2006) and had the texture of loamy sand. The soil was slightly acidic (pH in 1 mol/dm^3 KCl = 6.51), with organic carbon, total nitrogen and mineral nitrogen content of 7.65 g/kg, 0.94 g/kg and 10.25 mg/kg, respectively, and the following concentrations of available nutrients: P – 49.0 mg/kg, K – 96.4 mg/kg, Mg – 31.0 mg/kg. Experimental plot area was 20 m^2. The following four-year crop rotation sequence was applied: winter triticale, winter rapeseed, winter wheat and maize grown for silage. The effect of increasing MBM doses (1.0, 1.5, 2.0 and 2.5 t/ha/year and 2.0, 3.0, 4.0, and 5.0 t/ha/every second year) was compared to the NPK fertilizers applied to the control treatment (recommended mineral fertilizer rates for the tested crops). The direct and residual effects of the same MBM dose were also compared. In the treatment with NPK fertilization, nitrogen was applied as urea (46% N) or ammonium nitrate (34% N), and phosphorus as granulated triple superphosphate (20.1% P). MBM contained small amounts of potassium (3.4 kg K per ton of MBM), which is why each year MBM was supplemented with potassium in the form of potash salt (49.8% K), at a rate corresponding to potassium fertilizer levels in the control treatment. The average amounts of nutrients supplied by mineral fertilizers and MBM are shown in Table 1. MBM used in the study was category 3 material which comprises animal by-products derived from the production of products intended for human consumption, and it was purchased from the animal by-products disposal plant Saria Poland in Długi Borek near Szczytno. MBM contained on average 96.5% of dry matter (DM), 71.4% of organic matter, 27.6% of crude ash, 136.9 g of crude fat, 78.8 g N, 46.7 g P, 3.42 g K, 100.3 g Ca, 6.8 g Na and 2.0 g/kg DM.

Soil samples were collected before the experiment and each year after harvest to determine pH in 1 mol KCl/dm^3 (soil: solution extraction ratio 1:2.5) by the potentiometric method and available phosphorus – by the Egner-Riehm method (DL) – (soil: solution extraction ratio 1:50). Plant samples were mineralized due to wet mineralization in concentrated sulfuric acid (VI) with hydrogen peroxide (H_2O_2) as the oxidizing agent. Mineralized samples were assayed for the content of phosphorus by the vanadium-molybdenum method (Panak 1997).

Table 1. Doses of nutrients (kg/ha) with meal and bone meal (MBM) and mineral fertilizer in four-years rotation

Treatment		Winter triticale 2006/7			Winter rape 2007/8			Winter wheat 2008/9			Maize 2010		
		N	P	K	N	P	K	N	P	K	N	P	K
		110.0	30.0	100.0	190.0	40.0	150.0	140.0	35.0	120.0	150.0	40.0	140.0
Yearly	1.0 t MBM + K	78.8	46.7	103.4	78.8	46.7	153.4	78.8	46.7	123.4	78.8	46.7	143.4
	1.5 t MBM + K	118.2	70.1	105.1	118.2	70.1	155.1	118.2	70.0	125.1	118.2	70.1	145.1
	2.0 t MBM + K	157.6	93.4	106.8	157.6	93.4	156.8	157.6	93.4	126.8	157.6	93.4	146.8
	2.5 t MBM + K	197.0	116.7	108.5	197.0	116.7	158.5	197.0	116.7	128.5	197.0	116.7	148.5
Every two years	2.0 t MBM + K	157.6	93.4	105.1	0	0	150.0	157.6	93.4	126.8	0	0	140.0
	3.0 t MBM + K	236.4	140.1	110.2	0	0	150.0	236.4	140.1	130.2	0	0	140.0
	4.0 t MBM + K	315.2	186.8	113.6	0	0	150.0	315.2	186.8	133.6	0	0	140.0
	5.0 t MBM + K	394.0	233.5	117.0	0	0	150.0	394.0	233.5	137.0	0	0	140.0

MBM + K – meat and bone meal with potassium dose as in mineral fertilization

The results were verified statistically by the least squares method using Statistica 10 software (StatSoft 2010). The phosphorus content of soil was analyzed by two-way ANOVA where experimental factor I was MBM dose and experimental factor II was the year of the study (four consecutive years). The phosphorus content of crop plants was analyzed by one-way ANOVA. The significance of differences between arithmetic means was estimated by the Tukey's test at $P \leq 0.05$.

Meteorological conditions. The weather conditions during the four years of the field trials (2006–2010) were varied, primarily, in terms of rainfall distribution (Table 2). The growth and development of the tested crops took place at temperatures 0.7°C higher than the mean temperatures from 1961–2000. The high temperatures during the experiment should have been favourable to the release and activation of nutrients from meat and bone meal, but the changing precipitations, especially in the second and third year of the research, did not stimulate this process. According to Bassirirad (2000), soil temperature and moisture have a strong effect on the rate of metabolic processes in soil organisms which decompose organic matter and in microorganisms which indirectly influence the rate of its decomposition.

RESULTS AND DISCUSSION

It was assumed that due to its high calcium content (100 kg Ca per ton); MBM should act as a liming agent and raise the pH of soil. The soil used in the present experiment was slightly acidic (pH_{KCl} = 6.51). Four-year application of increasing MBM doses insignificantly decreased soil pH, regardless of the frequency of application, but it did not change soil classification based on pH ranges (pH_{KCl} = 6.36 was noted in the last year of the study on average) (Table 3). In comparison to the mineral fertilizers, higher doses of MBM applied every year lowered soil pH, despite the supply of considerable amounts of calcium (ca. 200–250 kg Ca/ha). The above suggests that the acidifying effect of nitrogen released during mineralization from MBM in the form of ammonia was stronger than the buffering effect of calcium. Svoboda et al. (2010) also reported a slight (0.1–0.2) decrease in the pH of soil amended with MBM. In our study, regular low-dose application of MBM (in particular 1.0 t/ha) led to an increase in soil pH by improving the sorption capacity of soil. Soil acidification could result from the activity of nitrifying microorganisms whose proliferation is stimulated by organic wastes, and high sulfate concentrations (Bohacz and Korniłowicz-Kowalska 2005).

An opposite trend was observed when MBM was applied every two years – soil pH increased with increasing doses of MBM, with the exception of 4.0 t MBM/ha in the second year of the study. Despite to the rise of soil pH, its values remained within the range typical for slightly acidic soils. The findings of other authors are inconclusive and often contradictory because they are affected by various factors such as soil type, type of animal offal and method of its processing, weather conditions and experiment duration (Bohacz and Korniłowicz-Kowalska 2005). Stępień and Mercik (2002) reported a decrease in the pH of soil amended with MBM, horn meal and feather meal, whereas Spychaj-Fabisiak et al. (2007) did not observe differences in soil pH after the application of a conditioner based on poultry offal. Valenzuela et al. (2001) and Deydier et al. (2003) noted an increase in the pH value of soil amended with MBM.

After four-year crop rotation, the average available phosphorus content of soil increased from the initial value of 78.0 to 86.34 mg P/kg (11% increase) in treatments with MBM and to 82.23 mg P/kg (approx. 5% increase) in treatments with mineral fertilization (Table 3). 47 kg P/ha was introduced into the soil with one ton of MBM. MBM applied every year led to a significant increase of available phosphorus levels, compared to the soil fertilized using mineral fertilizers, except for the lowest MBM dose (1.0 t/ha). Throughout the experiment, available phosphorus concentrations in soil increased, and soil pH decreased with

Table 2. Weather conditions in 2006–2010 according to the Research Station in Tomaszkowo

	2006	2007	2008	2009	2010	1961–2000
Average air temperature (°C)	7.8	8.6	8.9	7.8	6.8	7.3
Total rainfall (mm)	655.7	764.4	447.2	532.3	732.4	570.5

Table 3. Direct and residual effect of increasing doses of meal and bone meal (MBM) on the pH_{KCl} of soil and on the content of phosphorus (mg P/kg) available in soil

Treatment		2007		2008		2009		2010		Mean for *a*
		pH	P	pH	P	pH	P	pH	P	
Control NPK		6.59	85.76	6.49	85.89	6.66	72.94	6.48	82.23	81.71
Yearly	1.0 MBM + K	6.74	88.18	6.52	89.29	6.68	74.99	6.55	82.83	83.82
	1.5 MBM + K	6.70	90.88	6.40	91.43	6.65	74.82	6.51	86.17	85.82
	2.0 MBM + K	6.44	93.86	6.17	90.79	6.42	80.10	6.35	84.20	87.24
	2.5 MBM + K	6.33	96.17	6.12	95.22	6.28	86.47	6.29	88.72	91.65
Every two years	2.0 MBM + K	6.32	77.60	6.27	93.02	6.24	67.37	6.18	82.77	80.19
	3.0 MBM + K	6.46	89.36	6.37	93.25	6.35	70.27	6.24	88.74	85.41
	4.0 MBM + K	6.50	90.74	6.29	93.17	6.36	71.07	6.28	86.49	85.37
	5.0 MBM + K	6.58	94.40	6.48	96.89	6.59	79.37	6.47	90.77	90.36
Mean for *b*		–	89.66	–	92.11	–	75.27	–	85.88	–
$LSD_{0.05}$		$a = 3.79$; $b = 2.53$; $a \times b$ = ns								

MBM + K – meat and bone meal with potassium dose as in mineral fertilization; *a* – dose of MBM; *b* – years of research; $a \times b$ – interaction; ns – no significant difference

increasing MBM doses. In a study by Simoes et al. (2012), the levels of plant-available phosphorus in soil amended with MBM were also determined by the MBM dose. MBM applied at 43,6, 87,2 and 130,8 P/ha supplied 94, 66 and 78% available phosphorus, respectively. In the current study, MBM applied every second year contributed to a significant increase in the available phosphorus content in soil only at the highest dose (5.0 t MBM/ha). It should be noted that the only (2%) decrease in available phosphorus levels, compared to the NPK treatment, was observed when MBM was applied every two years at the lowest dose (2.0 t/ha). Stępień and Mercik (2002) analyzed different types of organic wastes from meat processing plants, including animal offal, and found that MBM was the most effective in increasing the available phosphorus content of soil. Bohacz and Korniłłowicz-Kowalska (2005) also demonstrated that composted poultry offal considerably increased the concentrations of plant-available phosphorus in soil.

The available phosphorus content in soil was significantly lower in the third and fourth year of the study, compared to the first and second year (Table 3). A measure of effective phosphorus utilization provided by MBM and other fertilizers of the type is their residual effect, which was observed in the second and fourth year of the study, relative to the corresponding doses of MBM applied each year. The residual effect of MBM resulted in a slightly higher average content of available phosphorus in soil, in comparison to the annual application. At low availability of phosphorus during the first growing season, MBM can be the main source of this nutrient for crop plants in subsequent years, and phosphorus fertilization is not recommended in the following year (Valenzuela et al. 2001, Jeng et al. 2006, Arvanitoyannis and Ladas 2008). According to Ylivainio et al. (2008), only 20% of phosphorus provided by MBM was available to plants in the first year, whereas 60% was still found three years after MBM application. Jeng et al. (2006) reported that as much as 50% of phosphorus from MBM was available to plants already in the first year. The rate of the process is difficult to explain because in soils with moderate available phosphorus levels the plants are able to obtain phosphorus from soil reserves. The fertilizing effect of MBM is much higher in phosphorus-deficient soils (Brod et al. 2012).

Throughout the experiment, the phosphorus content in soil was affected not only by MBM dose and frequency of application, but also by crop species and weather conditions. Winter triticale, which was grown in the first year of the study, was characterized by the lowest phosphorus uptake (18.7 kg P/ha on average), which explains a higher phosphorus content of soil noted in this year (Table 4). Winter wheat, which was grown in the third year, i.e. when soil phosphorus levels were

Table 4. Direct and residual effect of increasing doses of meal and bone meal (MBM) on the content (g/kg) in grain/seeds and uptake (kg/ha) of phosphorus by whole plants

Treatment		Winter triticale 2006/7		Winter rape 2007/8		Winter wheat 2008/9		Maize (whole plants) 2010	
		content	uptake	content	uptake	content	uptake	content	uptake
Control NPK		2.14	19.26	4.52	52.61	4.09	32.81	3.42	69.61
Yearly	1.0 t MBM + K	2.31	16.87	1.07	45.98	4.05	28.17	3.43	61.46
	1.5 t MBM + K	2.22	19.91	1.21	46.45	4.06	36.26	3.53	70.94
	2.0 t MBM + K	2.20	18.69	1.13	38.81	3.93	33.69	3.39	72.54
	2.5 t MBM + K	2.18	19.73	1.16	43.93	4.66	42.87	3.45	70.86
Every two years	2.0 t MBM + K	2.10	17.43	1.18	45.45	4.81	42.59	3.59	72.70
	3.0 t MBM + K	2.25	19.10	1.43	47.43	4.66	48.22	4.08	92.15
	4.0 t MBM + K	2.27	18.41	1.21	38.70	4.64	44.62	3.62	68.99
	5.0 t MBM + K	2.24	18.85	1.12	38.96	4.48	49.03	3.50	74.52
$LSD_{0.05}$		ns	ns	ns	ns	ns	6.17	ns	13.89

MBM + K – meat and bone meal with potassium dose as in mineral fertilization; ns – no significant difference

lowest (75.3 mg P/kg on average), was characterized by lower phosphorus uptake (39.8 kg P/ha on average) than winter rapeseed (44.3 kg P/ha on average) and maize (72.6 kg P/ha on average). During the four-year study, the lowest temperatures were noted during the growing season of 2008/2009, when winter wheat was grown. Slower release and mobilization of phosphorus provided by MBM could also result from a considerable water deficit in 2009. On the other hand, winter wheat grain was abundant in phosphorus, which testifies to a high phosphorus supply. In comparison to the NPK treatment, a significantly higher phosphorus content was noted in the grain of winter wheat grown in soil amended with MBM applied each year at the highest dose (2.5 t/ha) and every two years at 2.0, 3.0 and 4.0 t/ha (to winter triticale and winter wheat). Winter triticale and maize had higher phosphorus contents in MBM treatments than in NPK treatments, whereas the phosphorus content of rapeseed was lower, but the observed differences were statistically non-significant. Soil samples collected from winter rapeseed plots contained the largest quantities of available phosphorus (92.11 mg P/kg on average), which suggests that the plants had easy access to this nutrient. The beneficial influence of MBM on phosphorus content in various crop species was also reported by other authors (Stępień and Mercik 2002, Ylivainio et al. 2008, Nogalska et al. 2012). International scientific literature provides scant information on the use of MBM in maize cultivation (Chaves et al. 2005, Venegas 2009, Nogalska et al. 2012), and the combination of organic and mineral fertilizers is believed to increase maize productivity (Černý et al. 2012). The results of our study indicate that MBM is a valuable source of phosphorus for grain crops and, in particular, silage maize.

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