SCIENTIFIC NOTE

The effect of increasing doses of meat and bone meal (MBM) applied every second year on maize grown for grain

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Recently, due to the detection of cases of Bovine Spongiform Encephalopathy (BSE) in cattle, it has become necessary to use animal meals differently. The EU Council Decision of 4 December 2000 forbade use of processed animal protein to make feeds for cattle, swine, and poultry. Meat and bone meal (MBM) is rich in macro- and microelements as well as in organic substance, and hence it can be a viable alternative to mineral fertilizers containing N and P. The objective of this study was to determine the effect of increasing doses of MBM applied every second year as an organic fertilizer on maize (*Zea mays* L.) grown for grain. A two-factorial field experiment with a randomized block design was carried out in 2010-2011, in north-eastern Poland. Experimental factor I was MBM dose (2.0, 3.0, 4.0, and 5.0 Mg ha^{-1} applied every second year), and experimental factor II was the year of the study (two consecutive years). Increasing MBM doses applied every second year increased maize grain yield and improved grain plumpness, in comparison with mineral fertilization. The highest yield-forming effect was observed when MBM was applied at 3 Mg ha^{-1}. Macronutrient uptake by maize plants and macronutrient concentrations in maize grain were affected by the year of the study rather than MBM dose. The results of a 2-yr experiment indicate that MBM is a valuable source of N and P for maize grown for grain, and that it is equally or more effective when compared with mineral fertilizers.

Key words: Grain yield, macronutrients, meat and bone meal, uptake, TGW, *Zea mays*.

INTRODUCTION

Recent years have witnessed a growing interest in alternative and supplementary fertilizers produced by reusing of organic wastes including animal offal. Agricultural utilization of safe organic wastes is an important economic and environmental consideration since it allows using fertilizer components in plant production and improving the adsorption capacity of soil. Light and very light soils are predominant in Poland. Such soils are characterized by a fast rate of mineralization; therefore the application of organic wastes supports the stabilization mechanisms of soil organic matter. Recent research results show that animal meals, in particular meat and bone meal (MBM), are a rich source of N and P for crop plants (Górecka et al., 2009; Fernandes et al., 2010; Stępień, 2011; Chen et al., 2011; Brod et al., 2012; Nogalska et al., 2012). In addition, MBM has a high Ca content (*ca*. 110 kg Ca Mg^{-1}) which prevents soil acidification and reduces costs associated with liming (Jeng et al., 2004). MBM is a slow-working fertilizer because it contains organic N and P that are converted into plant-available forms with time.

Organic and natural fertilizers are efficiently used by maize (*Zea mays* L.), but international scientific literature provides scant information on the use of MBM in maize cultivation. In view of the above, the aim of this study was to determine the effect of increasing doses of meat and bone meal (MBM) applied every second year as an organic fertilizer on maize grown for grain.

MATERIALS AND METHODS

A field experiment was carried out in 2010-2011 at the Research and Experimental Station in Bałdy (53°60' N; 20°59' E), University of Warmia and Mazury in Olsztyn (NE Poland). The two-factorial experiment was performed in a randomized block design with four replicates, on soil with the granulometric composition of loamy sand, classified as Haplic Cambisol according to FAO (2006). The soil was slightly acidic (pH in 1 mol KCl dm^{-3} = 6.2), with organic C and total N content of 7.72 g and 0.96 g kg^{-1} DM, respectively, and the following concentrations of available nutrients: 49.2, 94.4, and 32.0 mg kg^{-1} DM for P, K, and Mg, respectively. Experimental plot area was 20 m^2. In the first and second year of the study, maize cv. San was grown for grain. The effect of increasing meat and bone meal (MBM) doses (2, 3, 4, and 5 Mg ha^{-1}), applied to the previous crop (winter wheat, *Triticum aestivum* L.)

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in the first year and to maize in the second year of the study, was compared with that of NPK fertilizers applied in the control treatment (recommended mineral fertilizer rates for maize: N - $160_{(60+50+50)}$, P - 39, K - 141 kg ha^{-1}). The average amounts of nutrients supplied by mineral fertilizers and MBM are shown in Table 1. Because MBM contained small amounts of K, it was classified as N-P fertilizer. Each year MBM was supplemented with K in the form of 60% potash salt, at a rate corresponding to K fertilizer levels in the control treatment. 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% DM, 71.4% OM, 27.6% crude ash, 136.9 g 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 Mg kg^{-1} DM.

Grain yield, thousand grain weight (TGW), mineral composition and macronutrient uptake by maize plants were determined. Plant samples were mineralized in concentrated sulfuric acid (VI) with hydrogen peroxide as the oxidizing agent. Wet mineralized samples were assayed for total N by the hypochlorite method, P by the vanadium-molybdenum method, Mg by atomic absorption spectrometry (AAS), Ca and K by atomic emission spectrometry (AES) (Panak, 1997). The results were verified statistically by ANOVA using STATISTICA 10 software. The significance of differences between arithmetic means was estimated by Tukey's test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Maize is highly sensitive to adverse weather conditions. This thermophilous plant has a high nutrient and water demand. In the first year of the study (2010), both temperatures and rainfall amounts were optimal for growing maize, with the exception of a cold and wet May (Table 2). July and August were conducive to cob development and ripening. The second year of the study (2011) was warmer than the first year and than the long-term average for this region, by 2 and 3 °C, respectively. The rainfall was unevenly distributed throughout the year 2011, which created less favorable conditions for maize growth and development. Rainfall excess in July (2.5-fold higher than the long-term average) and rainfall deficiency in September accelerated kernel ripening, leading to a lower grain yield. Alaru et al. (2003) demonstrated that weather conditions significantly affect the yield and quality of cereal grains. The rapid growth of maize fields in Poland testifies to climate change. Over the past decade, the total area under maize grown for grain has increased nearly ten-fold (Jaczewska-Kalicka, 2008).

Table 2. Average monthly temperatures and total monthly rainfall 2010-2011 according to the Research Station at Tomaszkowo.

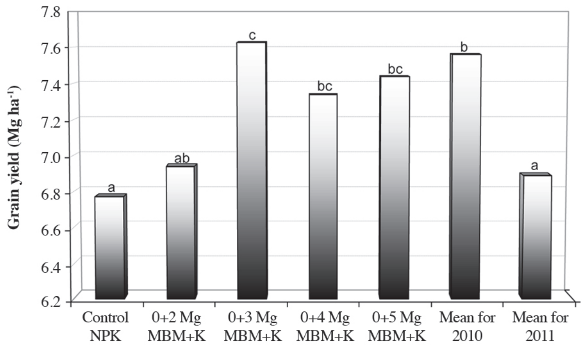
	Average monthly air temperatures			Total monthly rainfall		
Month	2010	2011	1970-2000	2010	2011	1970-2000
	°C			mm		
May	12.0	15.7	12.7	131.9	61.4	51.9
June	16.4	20.4	15.9	84.8	68.0	79.3
July	21.1	20.7	17.7	80.4	184.8	73.8
August	19.3	19.8	17.2	95.3	64.8	67.1
September	12.0	14.2	12.5	40.5	31.2	43.4
Mean	16.2	18.2	15.2	86.6	82.0	63.1

In the present experiment, maize was grown for grain with the use of MBM as N-P fertilizer, applied every second year. The average grain yield for 2 yr was 7.23 Mg ha^{-1} (Figure 1). Higher doses of MBM (3.0, 4.0, and 5.0 Mg ha^{-1}) significantly increased grain yield and TGW, in comparison with mineral fertilization (Figures 1 and 2). The highest average grain yield (7.63 Mg ha^{-1}) was achieved when MBM was applied at 3.0 Mg ha^{-1}. TGW increased with increasing MBM doses both years of the study. In the year following MBM application (residual effect), average grain yield was significantly higher and kernels were plumper than in the year when MBM was applied (direct effect). This could be due to unfavorable weather conditions in the second year, in particular uneven rainfall which, together with ambient temperature, affects the availability of nutrients provided by MBM and their subsequent utilization by plants. According to Klimek (2006), soil temperature and moisture content have a considerable effect on the rates of microbial metabolism and OM decomposition. In our previous study (Nogalska et al., 2012), lower doses of MBM (from 1.0 to 2.5 Mg ha^{-1}) applied every year resulted in a substantially lower grain yield (6.5 Mg ha^{-1} on average). This suggests that the after-effect of higher MBM doses contributed to a higher grain yield than the direct effect of lower MBM doses. Since the yield-forming effect of MBM was not dependent on the frequency of application, it is recommended to use this fertilizer every second year at higher doses. In greenhouse trials conducted by Chaves et al. (2005), increasing doses of two types of MBM had a beneficial

Table 1. Dose of N, P, and K (kg ha^{-1}) applied with mineral fertilizers and meat and bone meal (MBM) for preceding crop and maize.

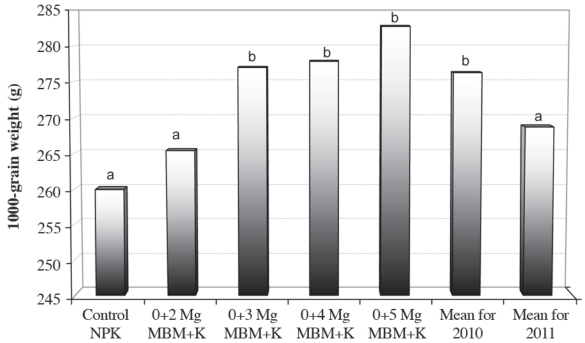
	(2009) Winter wheat (preceding crop)			(2010) Maize			(2011) Maize		
Treatment	N	P	K	N	P	K	N	P	K
Control NPK	160.0	39.0	141.0	160.0	39.0	141.0	160.0	39.0	141.0
2+0+2 Mg MBM+K	157.6	93.4	147.8	0	0	141.0	157.6	93.4	147.8
3+0+3 Mg MBM+K	236.4	140.1	151.2	0	0	141.0	236.4	140.1	151.2
4+0+4 Mg MBM+K	315.2	186.8	154.6	0	0	141.0	315.2	186.8	154.6
5+0+5 Mg MBM+K	394.0	233.5	158.0	0	0	141.0	394.0	233.5	158.0

MBM+K - meat and bone meal applied with K mineral fertilizers, 2+0+2, 3+0+3, 4+0+4 and 5+0+5 - MBM doses in 3 yr (Mg ha^{-1}).



Values associated with the same letter are not significantly different according to Tukey's test (P ≤ 0.05).
MBM+K - meat and bone meal applied with potassium mineral fertilizers.

Figure 1. The effect of doses of meat and bone meal (MBM) on the grain yield (Mg ha^{-1}) of maize, moisture 15%.



Values associated with the same letter are not significantly different according to Tukey's test (P ≤ 0.05).
MBM+K - meat and bone meal applied with K mineral fertilizers.

Figure 2. 1000-grain weight (TGW) (g) of maize, moisture 15%.

influence on corn yield. The high residual fertilizing value of both meals was evidenced by a good corn yield, which was comparable with those achieved in treatments with mineral fertilization. Satisfactory corn yields after the application of MBM at different doses were also reported by Venegas (2009). Stępień (2011) found no significant differences in cereal grain yield between treatments with MBM and mineral fertilization.

Over a 2-yr experimental period, the average N content of maize grain ranged from 16.11 to 21.09 g kg^{-1} DM, depending on MBM dose (Table 3). The highest N content was noted at MBM dose of 3.0 Mg ha^{-1}. The highest dose of MBM (5.0 Mg ha^{-1}) caused a significant decrease in the N content of maize grain, as compared with mineral fertilization and lower MBM doses. Different results were obtained at the highest dose of MBM (2.5 Mg ha^{-1}) applied every year, and only this dose supplied the amount of N comparable with that noted in control plants (Nogalska et al., 2012). In a study by Berenguer et al. (2008), the N content of maize grain was lower and varied between 11.3 and 17.1 g kg^{-1} DM. In the current study, maize grain harvested from treatments fertilized with different doses of MBM, had a higher average content of P (from 4.76 to 4.90 g kg^{-1} DM) and Mg (from 1.69 to 1.82 g kg^{-1} DM), compared with treatments with mineral fertilization, but differences were non-significant. An increase in the P content of grasses fertilized with MBM was also observed by Ylivainio et al. (2008), Nogalska (2011), and Nogalska et al. (2011). In our experiment, average Ca concentrations in maize kernels harvested from plants fertilized with MBM and NPK were similar. In all treatments (including those fertilized with MBM), 141 kg K was applied as 60% potash salt, because 1 Mg of MBM provides only 3.4 kg K. MBM (all doses) supplemented with mineral K contributed to a significant increase in the average K content of maize grain, in comparison with treatments with mineral fertilization. Considerable differences in the K content of maize kernels were observed in the second year of the study. In the first year, when only mineral K was applied, K concentrations were similar in all treatments. Such an effect was also noted after annual application of MBM with potash salt (Nogalska et al., 2012). According to Csatho (2002), K accumulation in plants is determined mostly by weather conditions, maize cultivar and an optimum supply of N and P.

Table 3. Macroelements content (N, P, K, Mg, Ca) of the grain of maize in different meat and bone meal (MBM) treatments.

Macronutrient	Year	Control NPK	0+2 Mg MBM+K	0+3 Mg MBM+K	0+4 Mg MBM+K	0+5 Mg MBM+K	Mean for years
		g kg^{-1}					
N	2010	16.36	14.29	15.07	15.60	11.19	14.50a
	2011	22.54	24.12	27.12	22.28	21.03	23.42b
Mean for dose		19.45bc	19.21b	21.09c	18.94b	16.11a	-
P	2010	4.22	4.13	4.35	4.17	4.29	4.23a
	2011	4.90	5.52	5.17	5.41	5.50	5.30b
Mean for dose		4.56	4.82	4.76	4.79	4.90	-
K	2010	3.89a	3.98a	4.25a	4.07a	3.84a	4.01a
	2011	6.19b	7.43d	6.97c	7.37cd	7.60d	7.11b
Mean for dose		5.04a	5.70b	5.61b	5.72b	5.72b	-
Mg	2010	1.42	1.33	1.37	1.29	1.39	1.36a
	2011	1.79	2.14	2.02	2.12	2.24	2.06b
Mean for dose		1.60	1.73	1.69	1.70	1.82	-
Ca	2010	0.29	0.25	0.31	0.25	0.25	0.27a
	2011	0.44	0.49	0.46	0.49	0.49	0.47b
Mean for dose		0.37	0.37	0.38	0.37	0.37	-

Values associated with the same letter are not significantly different according to Tukey's test (P ≤ 0.05).

Maize grain harvested in the year when MBM was applied (2011) accumulated higher amounts of the analyzed macronutrients (by over 1.5-fold on average) than maize plants grown in the first year (residual effect of MBM), most probably due to higher availability of soil nutrients released by mineralization of the animal meal. The yield and quality of maize grain are determined by numerous factors acting on plants during the growing season. In our previous study (Nogalska et al., 2012), the concentrations of mineral nutrients in maize grain were also higher after annual application of MBM. An important role was played by weather conditions which contributed to a lower yield of high-quality grain.

Nitrogen uptake by maize plants was significantly higher in the second year of the study (Table 4). Since in this year maize grain yield was lower (by *ca*. 0.7 Mg ha^{-1} on average), higher N uptake was mostly due to a considerably (by *ca*. 1.6-fold) higher N content of grain, compared with the first year. The higher N content of maize grain and higher N uptake could result from a direct effect of high MBM doses in the second year of the experiment, which increased N availability to plants. However, contrary to expectations, MBM applied at the highest dose (5 Mg ha^{-1}) did not contribute to the highest N uptake; actually, N uptake was lowest in this treatment at 181.5 kg N ha^{-1} on average. In comparison with the NPK treatment, N uptake was significantly higher in soil enriched with 3 Mg MBM ha^{-1}. Nutrients contained in MBM are found in both the organic meat and the inorganic bone fractions, the latter being released at a much slower rate than the former. Jeng et al. (2004; 2006) showed a fertilization effect of 80% of total N in MBM already in the first growing season.

Phosphorus uptake by maize plants was significantly higher in treatments with MBM than in treatments with mineral fertilization. This testifies high utilization of P supplied by MBM, which was also observed in an earlier experiment (Nogalska et al., 2012). Phosphorus uptake was highest (54.5 kg ha^{-1} on average) when MBM was applied at 3 Mg ha^{-1}. In comparison with the NPK treatment, P uptake increased by approximately 23%. Phosphorus uptake by maize plants was higher in the first year of the study (residual effect of MBM) than in the second year when higher N uptake was noted. This indicates that the rate of P mobilization is slower, compared with N. The rates of P solubility and release from animal bones are relatively slow, and depend mostly on soil pH. The readily available P (ammonium lactate extractable P) of fresh MBM represented 33-40% of its total P, and MBM-P efficiency was *ca*. 50% as compared with mineral P in the first year (Jeng et al., 2006). According to Warren et al. (2009), animal meals are a richer source of available P for crops than phosphates.

Average K uptake by maize plants varied from 218.1 to 243.6 kg ha^{-1}, depending on MBM dose applied with potash salt. Potassium accumulation in maize grain was significantly higher in MBM-fertilized treatments, in comparison with the NPK treatment. Since K fertilization was applied at the same level in all treatments each year, the above could be due to a balanced supply of the remaining nutrients to plants. MBM applied at 3 and 5 Mg ha^{-1} every second year contributed to significantly higher Mg uptake by maize plants, as compared with the NPK treatment. Magnesium and Ca uptake was significantly higher in 2010 than in 2011 when maize plants accumulated smaller amounts of those nutrients. Górecka et al. (2009) demonstrated that macronutrient concentrations and uptake by spring rapeseed plants fertilized with MBM were comparable with those noted following the application of mineral fertilizers. Satisfactory results were also reported for other crop species by Jeng et al. (2004; 2006), Sempiterno et al. (2010), Nogalska (2011), and Nogalska et al. (2011).

CONCLUSIONS

Increasing MBM doses applied every second year increased maize grain yield and improved grain

Table 4. Uptake of macroelements (N, P, K, Mg, Ca) in maize (whole plants) in different meat and bone meal (MBM) treatments.

Macronutrient	Year	Control NPK	0+2 Mg MBM+K	0+3 Mg MBM+K	0+4 Mg MBM+K	0+5 Mg MBM+K	Mean for years
		kg ha^{-1}					
N	2010	188.7	168.1	198.6	179.4	141.8	175.3a
	2011	216.8	236.2	285.4	247.1	221.3	241.4b
Mean for dose		202.7ab	202.2ab	242.0c	213.2bc	181.5a	-
P	2010	49.7	53.0	61.1	51.6	53.0	53.7b
	2011	38.7	50.0	47.8	49.6	49.6	47.1a
Mean for dose		44.2a	51.5b	54.5b	50.6b	51.3b	-
K	2010	209.5b	204.6b	252.3c	219.4bc	238.9bc	224.9
	2011	143.3a	231.6bc	216.9bc	243.6c	221.9bc	211.5
Mean for dose		176.4a	218.1b	234.6b	231.5b	230.4b	-
Mg	2010	16.7	17.9	19.8	16.8	20.7	18.4
	2011	15.2	17.8	17.1	19.4	19.4	17.8
Mean for dose		15.9a	17.8ac	18.5bc	18.1ab	20.1b	-
Ca	2010	54.0	52.6	65.2	48.4	57.6	55.6b
	2011	46.1	39.7	42.2	49.1	50.0	45.4a
Mean for dose		50.1	46.2	53.7	48.8	53.8	-

Values associated with the same letter are not significantly different according to Tukey's test ($P \leq 0.05$).

plumpness, in comparison with mineral fertilization. Macronutrient uptake by maize plants and macronutrient concentrations in maize grain were affected by the year of the study rather than MBM dose. Maize plants grown in the second year of the study (direct effect of MBM) were characterized by a higher content of the analyzed macroelements, higher uptake of P, K, Mg and Ca, and lower N uptake. Since the yield-forming effect of MBM was not dependent on the frequency of application, it is recommended to use this fertilizer every second year at higher doses. The results of a 2-yr experiment indicate that MBM is a valuable source of N and P for maize grown for grain, and that it is equally or more effective when compared with mineral fertilizers. However, further studies are needed to confirm the present findings.

LITERATURE CITED

Alaru, M., Ü. Laur, and E. Jaama. 2003. Influence of nitrogen and weather conditions on the grain quality of winter triticale. Agronomy Research 1:3-10.

Berenguer, P., F. Santiveri, J. Boixadera, and J. Lloveras. 2008. Fertilisation of irrigated maize with pig slurry combined with mineral nitrogen. European Journal of Agronomy 28:635-645.

Brod, E., T.K. Haraldsen, and T.A. Breland. 2012. Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment. Agricultural and Food Science 21:332-347.

Chaves, C., R. Canet, R. Albiach, J. Marin, and F. Pomares. 2005. Meat and bone meal: fertilizing value and rates of nitrogen mineralization. Nutrient and Carbon Cycling in Sustainable Plant-Soil Systems 1(6-9):177-180.

Chen, L., J. Kivela, J. Helenius, and A. Kangas. 2011. Meat bone meal as fertiliser for barley and oat. Agricultural and Food Science 20:235-244.

Csatho, P. 2002. The residual effect of K fertilization in a Hungarian corn monoculture long- term field trial, 1990-1999. Communication in Soil Science and Plant Analysis 33:3105-3119.

FAO. 2006. World Reference Base for Soil Resources. World Soil Resources Report 103:11-28. FAO, Rome, Italy.

Fernandes, R., C. Sempiterno, and F. Calouro. 2010. Meat and bone meal as nitrogen and phosphorus supplier to ryegrass (*Lolium multiflorum* L. var. Helen). II. Effects on soil N and P levels. In Marques dos Santos Cordovil, C.S.C., and L. Ferreira (eds.) Treatment and use of organic residues in agriculture: Challenges and opportunities towards sustainable management. 14th Ramiran International Conference Lisboa. 12-15 September 2010. Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Lisbon, Portugal.

Górecka, H., H. Sztuder, and U. Sienkiewicz-Cholewa. 2009. Agricultural usefulness of fertilization products obtained from the utilization of wastes from animal production. Zeszyty Problemowe Postępów Nauk Rolniczych 537:125-133.

Jaczewska-Kalicka, A. 2008. Influence of climate changes on yielding and cereal protection in Poland. Progress in Plant Protection 48:415-425.

Jeng, A.S., T.K. Haraldsen, A. Grønlund, and P.A. Pedersen. 2006. Meat and bone meal as nitrogen and phosphorus fertilizer to cereals and ryegrass. Nutrient Cycling in Agroecosystems 76:183-191.

Jeng, A.S., T.K Haraldsen, N. Vagstad, and N. Grønlund. 2004. Meat and bone meal as nitrogen fertilizer to cereals in Norway. Agricultural and Food Science 13:268-275.

Klimek, B. 2006. Effect of temperature on the rate and decomposition processes of organic matter in soil. Wiadomości Ekologiczne 52(3):123-142.

Nogalska, A. 2011. The effect of increasing doses of meat and bone meal on the yield and macronutrient content of timothy grass (*Phleum pratense* L.) Fertilizers and Fertilization 43:58-66.

Nogalska, A., J. Czapla, Z. Nogalski, M. Skwierawska, and M. Kaszuba. 2012. The effect of increasing doses of meat and bone meal (MBM) on maize (*Zea mays* L.) grown for grain. Agricultural and Food Science 21:325-331.

Nogalska, A., J. Czapla, and M. Skwierawska. 2011. The effect of increasing doses of meat-and-bone meal on the yield and macronutrient content of perennial ryegrass (*Lolium perenne* L.) Polish Journal of Natural Sciences 26:5-13.

Panak, H. 1997. Methodical guide to agricultural chemistry. Wydawnictwo ART, Olsztyn.

Sempiterno, C., R. Fernandes, and F. Calouro. 2010. Meat and bone meal as nitrogen and phosphorus supplier to ryegrass (*Lolium multiflorum* L. var Helen). I. Dry matter yield. N and P uptake and apparent N and P recovery. In Marques dos Santos Cordovil, C.S.C., and L. Ferreira (eds.) Treatment and use of organic residues in agriculture: Challenges and opportunities towards sustainable management. 14th Ramiran International Conference, Lisboa. 12-15 September 2010. Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Lisbon, Portugal.

Stępień, A. 2011. The effect of meat and bone meal on soil properties and crop yield. Dissertations and Monographs 161:1-110.

Venegas, F. 2009. Efeito de doses de farinha de carne e ossos como fonte de fosforo na producao de milho verde (*Zea mays* L.) Ensaios e Ciencia, Ciencias Biologicas, Agrarias e da Saude 23:63-76.

Warren, G.P., J.S. Robinson, and E. Someus. 2009. Dissolution of phosphorus from animal bone char in 12 soils. Nutrient Cycling in Agroecosystems 84(2):167-178.

Ylivainio, K., R. Uusitalo, and E. Turtola. 2008. Meat bone meal and fox manure as P sources for ryegrass (*Lolium multiflorum*) grown on a limed soil. Nutrient Cycling in Agroecosystems 81:267-278.