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# Meat and bone meal as nitrogen and phosphorus supplier to cereals and oilseed rape

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The purpose of this study was to evaluate the effect of meat and bone meal (MBM) on cultivation of winter triticale, winter oilseed rape, winter wheat and maize. The average annual yields and protein yield achieved in crop rotation were studied. The field trials were carried out in north-eastern Poland in 2006–2010. The factor was dose of MBM: 1.0, 1.5, 2.0 and 2.5 t $ha^{-1}$ $year^{-1}$ or 2.0, 3.0, 4.0 and 5.0 t $ha^{-1}$ every other year. The four-year experiment has proven that MBM is a valuable nitrogen and phosphorus fertilizer in cultivation of cereals and oilseed rape. By amendment of the tested meal into the soil it produced crop yield and protein yield similar to that achieved by mineral fertilization. However, the crude fat yield of rape was significantly higher under the influence of all the MBM doses. The yield-stimulating effect of MBM did not depend on the frequency of its application; therefore it is more convenient to apply it once every two years. Increasing MBM from 1.5 to 2.5 t $ha^{-1}$ did not significantly increase any of the four crop yields, therefore for soils that had satisfactory nutrients content, 1 or 1.5 t $ha^{-1}$ MBM is enough and increasing MBM will only increase economic burden for farmers and environmental risks.

*Key words*: triticale, rape, wheat, maize, yield, meat and bone meal

## Introduction

For many years, animal meals have had little use as fertilizers, mainly because of a large-scale processing of slaughter by-products for production of high-protein animal feeds. Recently, due to the detection of cases of BSE (Bovine Spongiform Encephalopathy) 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. Many research centres have undertaken investigations on use of various slaughter by-products as fertilizers. Soil amendment with animal meals has proven to generate satisfactory yields of crops, especially cereals and grasses (Salomonsson et al. 1994, 1995, Jeng et al. 2004, 2006, Ylivainio et al. 2008, Fernandes et al. 2010, Sempiterno et al. 2010, Simoes et al. 2012). Currently, studies are carried out to evaluate the quality of yields after application of meat and bone meals or fertilizer products made from animal by-products (Chen et al. 2011, Stępień and Wojtkowiak 2011, Wojtkowiak and Stępień 2011).

Compared to farm yard manure (FYM), dry matter of MBM contains four-fold more nitrogen, 10-fold more phosphorus and 8-fold more calcium, but it is poorer in potassium (4-fold less than manure) and magnesium (half the amount in manure). The content of organic matter in both types of fertilizer is similar. A wide range of positive effects produced by animal meals on soil and consequently on plant production makes them an essential product on farms which do not generate natural fertilizers. Such questions as proper management of animal meals and their potential value as fertilizers have stimulated field experiments testing the applicability of MBM in cultivation of maize (Nogalska et al. 2012, Nogalska et al. 2013). Nutrients contained in meals 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 fertilization effect of 80% of the total N in MBM already in the first growing season. The readily available P (ammonium lactate extractable P) of fresh MBM represented 33–40% of its total P, and MBM-P efficiency was about 50% compared to mineral-P in the first year (Jeng et al. 2006). Maćkowiak (2005) claims that nitrogen and phosphorus release from animal meals continues for two years and is slightly slower than from manure. Ylivainio et al. (2008) said that phosphorus may release for more than five years in alkaline soils.

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The need to obtain higher yields and better yield quality encourages us to look for new or less known means of agricultural production. At present, attention is drawn to possible use of animal meals, rich in nitrogen and phosphorus as well as calcium and micronutrients, as an alternative to mineral nitrogen and phosphorus fertilizers and also a way of handling noxious biological by-products (Valenzuela et al. 2001, Arvanitoyannis and Ladas 2008, Stępień 2011, Brod et. al. 2012, Nogalska et al. 2012, Nogalska et al. 2013). Possible utilization of nutrients from animal meals depends primarily on their chemical composition and proper mixing with soil, soil pH value, species of crops and weather conditions (Stępień and Mercik 2002, Spychaj-Fabisiak et al. 2007, Górecka et al. 2009, Nogalska 2013, Nogalska and Zalewska 2013).

The following study has been performed in order to evaluate the direct and residual effect of incrementally higher rates of meat and bone meal on yields of winter triticale, winter oilseed rape, winter wheat and maize.

## Material and methods

A field experiment was carried out in 2006–2010 at the Research and Experimental Station in Bałdy, owned by the University of Warmia and Mazury in Olsztyn (NE Poland). The experiment was performed in a randomized block design with four replications. The gross experimental plots were 4 m times 5 metres, 20 m$^2$. The experiment simulated a four-year rotation of arable crops: the crops were winter triticale cv. 'Grenado' (2006–2007), winter oilseed rape cv. 'Rafaela' (2007–2008), winter wheat cv. 'Bogatka' (2008–2009), and silage maize cv. 'San' (2010). Effectively, each season, and each crop, was an experiment on its own, and the statistical testing for each season's data was done separately from the other seasons' data. The experiment was designed to enable us to compare the direct and residual effects of the same rates of meat bone meal (MBM) as fertilizer.

In the first season with winter triticale, the experimental factor was the rate of application of MBM as fertilizer, with seven levels from 1.0 to 5.0 t ha$^{-1}$. In the treatments, the inputs of N and P depended on MBM rate directly. The K input was controlled by adjusting the total K input with potassium salt (49.8% K), to achieve the same K input in each treatment (Table 1). The treatment with 2.0 t ha$^{-1}$ was repeated twice in each block, to allow the next season's treatments to be arranged.

In the second season with winter oilseed rape, the experimental factor was fertilization regime with 8 levels. The regimes varied in terms of the rate of MBM application, and in terms of the application being at the seedbed preparation or as residual effect from the previous season. The plots which received the four highest rates of MBM in the previous season, were left without MBM for this season. Hence, the idea was to test if applying high amounts every second year would give the same result as applying less every year. The rates were adjusted so that each treatment with yearly application had a parallel treatment in which double that amount was given for the previous crop (Table 1). This allowed testing the residual effect of MBM. Again, total K was adjusted to reach the same input for each treatment.

The two first seasons' fertilization scheme was repeated in the two last seasons. In the third season, as in the first season but now with winter wheat, there were seven MBM application rates as treatments (Table 1). In the fourth season, now with silage maize, the treatments were as in the second season.

The effect of increasing rates of MBM, i.e. 1.0, 1.5, 2.0, 2.5 t ha$^{-1}$ introduced annually and 2.0, 2.5, 3.0, 4.0, 5.0 t ha$^{-1}$ applied biannually, was tested (Table 1). In all seasons, for each crop, mineral fertilization (NPK) as recommended for the crop was included as a control treatment. In this control treatment, PK fertilizers were applied pre-sowing, while nitrogen was applied separately three times: first before sowing and two subsequent doses top dressing (Table 1).

The soil was Haplic Cambisols according to FAO (2006), and had the following properties: $pH_{KCl}$ = 6.3, total organic C 7.65 g kg$^{-1}$, total nitrogen 0.94 g kg$^{-1}$, available phosphorus 49.0 mg kg$^{-1}$, potassium 96.4 mg kg$^{-1}$ and magnesium 31.0 mg kg$^{-1}$ DM of soil. The soil pH was determined in 1 mol KCl, total organic matter was determined by Tiurin method, total nitrogen was determined by Kjeldahl method, available phosphorus and potassium were determined by Egner-Riehm method (DL), and available magnesium by Schachtschabel method (Panak 1997).

MBM contained small amounts of potassium, which is why it was classified as a nitrogen-phosphorus fertilizer. The MBM used in the study was in the form of powder and classified as category 3, which comprises animal by-products derived from manufacture 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 96.05% dry matter, 71.42% organic matter, 27.64% crude ash, 136.90 g crude fat, 78.80 g N, 46.71 g P, 3.42 g K, 100.30 g Ca, 6.81 g Na and 2.00 g Mg $kg^{-1}$ DM. Because MBM was characterized by a low potassium content (3.4 kg K per ton of MBM), each application of MBM to soil was combined with the incorporation of K in the form of potassium salt (49.8% K) in the amount corresponding to the quantity found in the control treatment. The doses of nutrients incorporated to soil with mineral fertilizers and MBM are presented in Table 1.

The yields of the crops in the rotation system were expressed as grain yields (given in 14.5% moisture content) for winter triticale and winter wheat, as seed yield (given in 9% moisture content) for rape, as well as in total protein yields, using the conversion index 6.25 x concentration of nitrogen in plants and crude fat yield for rape by gravimetric method after extraction with petroleum ether. Total nitrogen was determined by the hypochlorite method in plant material mineralized in concentrated sulphuric (VI) acid with addition of 30% hydrogen peroxide ($H_2O_2$) (Panak 1997). The results were verified statistically by ANOVA using STATISTICA 10 software. The significance of differences between means was estimated by Tukey's test at $p<0.05$.

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 $^{o}C$ 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 Klimek (2006), 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.

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

| Year | 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 1. The treatments in the experiment and doses of nutrients with meat and bone meal (MBM) and mineral fertilizer (kg ha$^{-1}$) in four-year 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 |
| Control (NPK) | | 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 | 106.8 | 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 |

# Results

## Yield of crops

We compared yields of the same crop at different rates of MBM fertilizations. For the second and fourth year, we compared the residual effects of every two years with yearly application of MBM. We also compared the effect of MBM and mineral NPK fertilizer at a similar N application rate.

Grain yield of winter triticale ranged from 3.70 to 5.69 t ha$^{-1}$. The highest grain yield of winter triticale (4.89 t ha$^{-1}$) upon MBM fertilization was achieved at 1.5 t ha$^{-1}$ MBM (Table 3); increasing MBM did not significantly increase grain yield, on the contrary often decreased grain yield. Compared to mineral fertilization which had the similar N level as 1.5 t ha$^{-1}$ MBM, grain yield did not differ between chemical fertilization and MBM.

For winter rape, the highest seed yield (4.2 t ha$^{-1}$) was obtained also at 1.5 t ha$^{-1}$ MBM fertilization, whereas most of the MBM fertilization rates also produced significant difference ($p$<0.05). The plots without fertilization had residual effects that gave winter rape similar yield as those applied yearly. Compared to mineral fertilization which had the similar N level as 2.5 t ha$^{-1}$ MBM, seed yield did not differ between chemical fertilization and MBM.

Table 3. Direct and residual effect of meat bone meal (MBM) rates on the yield of plants (t ha$^{-1}$). Values with the same superscripts are not significantly different at $p$< 0.05.

| Treatment | | Winter triticale (grain) (2006/7) | Winter rape (seed) (2007/8) | Winter wheat (grain) (2008/9) | Maize (whole plants) (2010) |
|---|---|---|---|---|---|
| Control NPK | | 5.69$^{b}$ | 3.00$^{a}$ | 4.88 | 20.4$^{ab}$ |
| Yearly | | | | | |
| | 1.0 t MBM+K | 4.38$^{a}$ | 3.96$^{b}$ | 4.08 | 17.9$^{a}$ |
| | 1.5 t MBM+K | 4.89$^{b}$ | 4.20$^{b}$ | 5.06 | 20.0$^{ab}$ |
| | 2.0 t MBM+K | 4.45$^{ab}$ | 3.73$^{ab}$ | 4.93 | 21.4$^{ab}$ |
| | 2.5 t MBM+K | 4.33$^{a}$ | 3.71$^{ab}$ | 5.66 | 20.5$^{ab}$ |
| Every two years | | | | | |
| | 2.0 t MBM+K | 4.02$^{a}$ | 3.97$^{b}$ | 5.40 | 20.2$^{ab}$ |
| | 3.0 t MBM+K | 3.70$^{a}$ | 4.15$^{b}$ | 6.49 | 22.7$^{b}$ |
| | 4.0 t MBM+K | 4.03$^{a}$ | 3.71$^{ab}$ | 6.07 | 19.0$^{ab}$ |
| | 5.0 t MBM+K | 4.33$^{a}$ | 3.74$^{b}$ | 6.74 | 21.5$^{ab}$ |

Grain yield of winter wheat was rather good (ranged from 4.08 to 6.74 t ha$^{-1}$) and increased along with the increase of MBM rate, however, the difference was not significant ($p$<0.05). Grain yield of winter wheat fertilized with NPK as also did not differ significantly from that fertilized with MBM ($p$<0.05).

The highest average dry matter yield (20.4 t ha$^{-1}$) was achieved in the last year, when maize was grown, although its yields were rather unstable, ranging from 17.9 to 22.7 t ha$^{-1}$. MBM applied in higher rates only caused a significant increase in the yield at the residual effect of 3 t ha$^{-1}$ MBM. Yields of maize at the same fertilization rate did not differ whether applied yearly or every two years. Compared to mineral fertilization which had the similar N level as 2 t ha$^{-1}$ MBM, maize yields did not differ between chemical fertilization and MBM.

## Protein yield

The highest protein yield was obtained in the third year by wheat (199.3 t ha$^{-1}$), followed by triticale (184.1 kg ha$^{-1}$), rape (173.3 kg ha$^{-1}$) and maize (63.6 kg ha$^{-1}$) (Table 4). The differences in protein yield in different species of crops were mainly due to the concentration of nitrogen in these plants.

Increasing doses of MBM, irrespective of application frequency, did not differentiate the protein yield for winter triticale, winter rape and winter wheat. Protein yield from crops grown on MBM-fertilized plots was similar to the control.

Table 4. Direct and residual effect of meat bone meal (MBM) rates on protein yield (kg ha$^{-1}$). Values with the same superscripts are not significantly different at *p*< 0.05.

| Treatment | | Winter triticale (2006/7) | Winter rape (2007/8) | Winter wheat (2008/9) | Maize (2010) |
|---|---|---|---|---|---|
| Control NPK | | 176.3 | 171.7 | 203.0 | 63.2$^{bc}$ |
| Yearly | 1.0 t MBM+K | 165.2 | 159.4 | 198.0 | 65.3$^{cd}$ |
| | 1.5 t MBM+K | 192.0 | 180.6 | 192.2 | 60.8$^{abc}$ |
| | 2.0 t MBM+K | 186.4 | 170.4 | 194.0 | 70.6$^{de}$ |
| | 2.5 t MBM+K | 187.1 | 177.4 | 201.9 | 73.9$^{e}$ |
| Every two years | 2.0 t MBM+K | 170.3 | 173.0 | 199.4 | 55.7$^{a}$ |
| | 3.0 t MBM+K | 203.1 | 181.2 | 195.6 | 62.6$^{abc}$ |
| | 4.0 t MBM+K | 187.5 | 165.1 | 200.8 | 62.6$^{abc}$ |
| | 5.0 t MBM+K | 189.2 | 181.2 | 208.7 | 57.8$^{ab}$ |

In our experiment, only protein yield of maize differed significantly at different rates of MBM, however the increase of protein yield was not linear to the increasing MBM rate. Compared to NPK which had the same N rate as 2 t ha$^{-1}$ MBM, the protein yield of maize was significantly higher under MBM fertilization than NPK.

## Crude fat yield

Crude fat yield (t ha$^{-1}$) produced from seeds of winter rape was observed to significantly increase upon the use of meat-bone meal, irrespective of the frequency of its application, as compared to mineral fertilization ($p$<0.05) (Fig. 1). On average, all MBM rates caused ca. 30% increase in crude fat yield of winter rape when compared to mineral fertilization (Fig. 1). The most beneficial effect of MBM was determined upon the use of the second rate in quantity, i.e. 1.5 t ha$^{-1}$ annually (direct effect 118 kg N ha$^{-1}$) or 3.0 t ha$^{-1}$ every two years (residual effect 236 kg N ha$^{-1}$), after which the yield of crude fat was high and accounted for 1.80 and 1.83 t ha$^{-1}$, respectively. It resulted in as high as 40% increase in oil yield at these plots, compared to plots with NPK fertilization. The poorest effects (1.62 t ha$^{-1}$ oil on average) were achieved in crop fertilized with the highest MBM rates. Worthy of notice is that in this case the direct and residual effects of animal meal were alike (157–197 kg N ha$^{-1}$ and 315–394 kg N ha$^{-1}$, respectively).

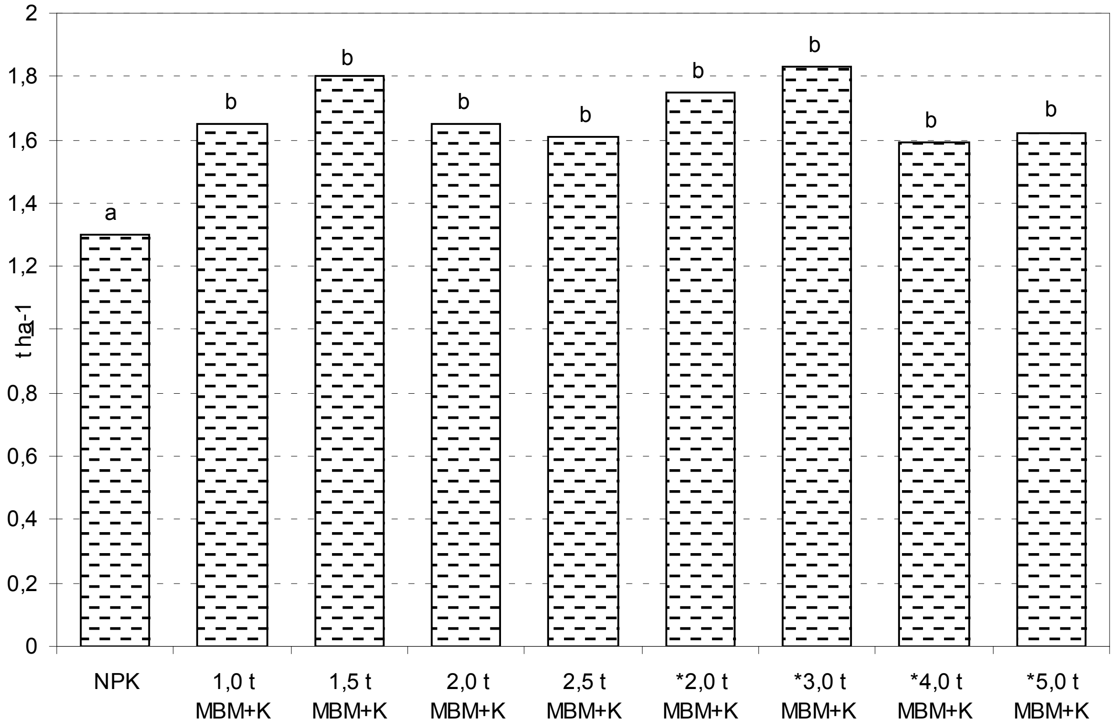


Fig. 1. Yield of crude fat (t ha$^{-1}$) of winter oilseed rape. *2.0, 3.0, 4.0, 5.0 MBM+K – residual effect. Values with the same superscripts are not significantly different at *p*< 0.05.

# Discussion

## Grain yield

In hypothesis, increasing rate of N will increase crop yields. Chen et al. (2011) found that increasing MBM N from 60 to 120 kg ha$^{-1}$ significantly increased barley yield. However, in our experiment, increasing N from 118 to 197 kg ha$^{-1}$ did not increase any of the four crops' grain yields. Moreover, in some cases, increasing rate of MBM decreased crop yields, especially over 2 t ha$^{-1}$ MBM (157.6 kg N ha$^{-1}$). One possible reason is that the soil had good nutrient contents and only small amount of fertilization would meet crops' needs for nutrients. Raising MBM from 1 to 2.5 t ha$^{-1}$ increased N from 78.8 to 197 kg ha$^{-1}$, which may exceed crops needs, therefore increasing rate of MBM hardly significantly increased crop yields.

Comparing MBM and NPK fertilizer at the same N rate, no significant differences were found in crop yields. The result is in accordance with Jeng et al. (2004), who found that N efficiency in MBM compared to mineral fertilizer was 80% or higher.

During the second and fourth year, the residual effect of MBM was tested and no significant difference was found between yearly and every two years application. Also during the two other analyzed years, no significant difference was found between different MBM rates that were applied the previous year. Therefore even the lowest MBM rate gave rather good crop yield. However, adding large amount of MBM at one time will increase the risk of nitrogen and phosphorus loading, therefore research on environmental risks of MBM is needed. Considering the economic and environmental prices of MBM fertilization, we recommend that for soils that had satisfactory nutrient composition, the minimal application rate of 1 t ha$^{-1}$ is enough.

## Protein yield

In the four-year rotation crop system, similar protein yields were obtained as a result of both the direct and residual effects of MBM irrespective of the rate of MBM, and they did not differ significantly from values achieved upon mineral NPK fertilizer. The results were similar to findings of previous studies. Stępień (2011) proved that the effect of MBM on protein yield in five-year crop rotation was similar to that produced by mineral fertilization and superior to FYM. Salomonsson et al. (1994, 1995) found no significant differences in protein yield for winter and spring wheat at different rates of MBM. However, Chen et al. (2011) found a significant increase in the protein yield of spring barley and oat when increasing N level of MBM from 60 to 120 kg $ha^{-1}$.

Only maize produced 12% lower yield at the residual than the direct effect of MBM. Similar results were reported from two-year trials on maize grown for grain (Nogalska et al. 2012, Nogalska at al. 2013). Some authors, however, suggest that MBM could be the main source of nitrogen, phosphorus and calcium for crops (Arvanitoyannis and Ladas 2008, Valenzuela et al. 2001). Some researchers (Stępień and Wojtkowiak 2011, Wojtkowiak and Stępień 2011) claim that MBM had a positive effect not only on the volume of protein yield but also on its quality.

## Crude fat yield

Based on results obtained in the study, a tentative conclusion may be formulated that the applied meat-bone meal, as a substitute for NP fertilizers, has a more beneficial effect on the yield of crude fat of winter rape than mineral fertilization does. A similar yield-stimulating effectiveness of the meal was proved in the direct and residual effect, however complete evaluation of MBM usability in rape cultivation requires further studies as sparse information is available in literature in this respect. According to Stępień (2011), mineral fertilization had a more beneficial effect than MBM on oil content of winter rape seeds. In turn, meal yielded better results of this trait compared to manure. In our study, the highest crude fat yield was obtained upon the medium MBM rate, whereas the higher rates exerted poorer effects on oil yield of rape. Usually, an increased level of nitrogen fertilization resulted in a decreased content of crude fat and a simultaneous increase in total protein content in seeds of winter rape (Kotecki et al. 2001, Jankowski et al. 2005). Opposite effects were reported in a study by Stępień (2011) – where the highest MBM rate (2.5 t $ha^{-1}$ used annually) was proved best in stimulating oil accumulation in rape seeds.

# Conclusions

The four-year experiment presented in this paper suggests that MBM can be a valuable nitrogen and phosphorus fertilizer for cereals and oilseed rape. The tested MBM produced similar effects as mineral fertilizer (NP) in terms of yield, protein yield of the grown crops and crude fat of oilseed rape seeds. Thus, if the yield-stimulating effect of animal meal did not depend on the frequency of its application, it is more economical and convenient for the farmer to use higher rates of this product once every two years.

Increasing rate of MBM from 1 to 2.5 t $ha^{-1}$ in many cases did not significantly increase yield, protein yield of crops and crude fat of oilseed rape seeds, therefore considering the economic and environmental prices, we recommend that for soil that had a satisfactory nutrients content, a low rate of MBM (1.5 t $ha^{-1}$) is enough. Higher MBM rates do not increase crop yields anymore and only cause economic burden for the farmers and increase risks of nitrogen and phosphorus loading.

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