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# Meat and bone meal as fertilizer for spring barley

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**ABSTRACT**

The aim of this study was to determine whether meat and bone meal (MBM) can be used as NP fertilizer for spring barley grown for fodder. A two-factorial field experiment was conducted in Poland. Experimental factor I was MBM dose (0, 1.0, 1.5, 2.0, 2.5 t/ha/year) which was compared to the mineral fertilization (NPK), factor II was the year of the study (two consecutive years). MBM used in doses higher than 1.0 t/ha had a more beneficial influence on the grain yield of spring barley and grain plumpness than mineral fertilizers. The positive yield-forming effect of MBM doses 2.0 t/ha and 2.5 t/ha was statistically significant. The nitrogen (N) content of grain was similar in treatments with MBM and mineral fertilization. The two highest MBM doses contributed to a significant decrease in the phosphorus (P) content of grain, particularly in the second year of the study, in comparison with the remaining MBM doses and mineral fertilizers. Grain yield and N content were also affected by the year of the study, due to weather conditions and the residual effect of MBM. The optimal MBM dose was 1.5 t/ha, which allowed to produce 5.1 t/ha of the plumpest grain whose N and P content was consistent with the feeding standards for livestock.

**Keywords**: *Hordeum vulgare* L.; thousand grain weight; NP content; uptake; animal meal

Barley (*Hordeum vulgare* L.) is a versatile cereal grain, and it has an approximately 10% share of global cereal production. Barley grain is used as livestock feed, for human consumption and in the brewing industry. Fertilization is one of the most important agronomic determinants of grain yield and quality. Barley is considered to be the most sensitive to soil acidification among cereal species, which is why barley yield is largely determined by liming. Meat and bone meal (MBM) can be a viable alternative to mineral fertilizers because it is rich in nitrogen (N), phosphorus (P), calcium (Ca) and organic matter that contributes to closed-cycle transfer of nutrients between soil and plants. Meat and bone meal contains N in the form of protein compounds, which is mineralized and gradually released into soil, becoming available to plants already in the first year after application (Jeng et al. 2004, Nogalska 2013, Stępień and Wojtkowiak 2015). Phosphorus is present in MBM in organic form (meat fraction), which is readily available to plants, and in the form of apatite (bone fraction). The release of phosphorus from apatite takes place in an acidic environment (Jeng et al. 2006). Due to its high calcium content (approx. 100 kg Ca/t), MBM can support liming the soil.

The results of previous studies investigating the effects of MBM, in particular its dose, on the yield and quality of barley are ambiguous and inconclusive (Jeng et al. 2004, 2006, Svoboda et al. 2010, Chen et al. 2011). In view of the above, the objective of this study was to determine whether MBM can be used as fertilizer for spring barley grown for fodder. An attempt was also made to determine the optimum MBM dose based on the N and P requirements of barley.

## MATERIAL AND METHODS

A field experiment was carried out in 2012–2013 at the Agricultural Experiment Station in Bałdy, owned by the University of Warmia and Mazury in Olsztyn (north-eastern Poland). The experiment

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was performed in a randomized block design with four replications, on soil that was classified as Haplic Cambisols according to the FAO (2014) and had the texture of loamy sand. The available nutrient content of soil was as follows: P – 64.0 mg/kg (moderate), K – 110.6 mg/kg (moderate), Mg – 26.5 mg/kg (low). The soil had a neutral pH of 6.67 in 1 mol/dm$^3$ KCl. The experimental factors were: increasing MBM doses and two consecutive years of the study. Spring barley cv. Eunova was grown for fodder on 24 plots (1 plot = 20 m$^2$).

In the control treatment, mineral fertilizers (NPK) were applied to meet the nutrient requirements of barley, and MBM was applied each year in the same plots in the following doses: 0 (no fertilizer), 1.0, 1.5, 2.0 and 2.5 t MBM/ha (Table 1). In the treatment with NPK fertilization, nitrogen was applied three times: pre-sowing – at 35 kg/ha N in the form of ammonium nitrate (34% N), in the tillering stage – at 40 kg N/ha, and in the heading stage – at 25 kg N/ha in the form of urea (46% N). Phosphorus was applied pre-sowing (40 kg P/ha) as granular triple superphosphate (20.1% P), potassium (110 kg K/ha) was applied as potash salt (49.8% K). 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, at a rate corresponding to potassium fertilizer levels in the control treatment (110 kg K/ha). According to the Regulation of the Ministry of Agriculture and Rural Development of 7 December 2004 the MBM used in this study was material of category 3, 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% of dry matter (DM), 710 g/kg organic matter, 280 g/kg crude ash, 137 g/kg crude fat, 78.8 g/kg N, 46.7 g/kg P, 3.42 g/kg K, 100.3 g/kg Ca, 6.8 g/kg Na and 2.0 g/kg Mg of DM.

Grain yield, thousand grain weight (TGW), total N and P content of grain, and uptake by barley biomass were determined. Plant samples were mineralized by wet mineralization in concentrated sulfuric acid (VI) with hydrogen peroxide as the oxidizing agent. Mineralized samples were assayed for the content of total N – by the hypochlorite method, and total P – by the vanadium-molybdenum method (Panak 1997). The results were verified statistically by the ANOVA using Statistica 10 software (StatSoft 2010). The significance of differences between mean values was estimated by the Fischer's test at a significance level of $P \leq 0.05$.

**Meteorological conditions**. In the first year of the study (2012), ambient temperature during the growing season was by 2.1°C higher than the respective long-term averages (1981–2010), whereas rainfall distribution was uneven (Table 2). Rainfall levels in April were over 3-fold higher than the long-term average. Under the climatic conditions of Poland, early sowing of barley occurs in the last week of March and in the first week of April, which contributes to deep rooting of plants. Rainfall excess (41 mm) noted in the first week of April 2012 delayed sowing, which took place on 18 April. After sowing, heavy rainfall and ambient temperature in the last week of April led to soil crusting, which resulted in thinning and uneven emergence. High ambient temperatures throughout the growing season, accompanied by heavy rainfall in June, led to the development of fungal pathogens on barley. In the second year of the study (2013), barley was also sown in mid-April.

Table 1. Doses of nitrogen (N), phosphorus (P) and potassium (K) applied with meat and bone meal (MBM) and mineral fertilizers (kg/ha) for spring barley in 2012–2013

| Treatment | 2012 | | | 2013 | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| O (no fertilizer) | 0 | 0 | 0 | 0 | 0 | 0 |
| Control NPK* | 100 | 40 | 110 | 100 | 40 | 110 |
| 1.0 t MBM + K** | 79 | 47 | 113 | 79 | 47 | 113 |
| 1.5 t MBM + K | 118 | 70 | 115 | 118 | 70 | 115 |
| 2.0 t MBM + K | 158 | 93 | 117 | 158 | 93 | 117 |
| 2.5 t MBM + K | 197 | 117 | 118 | 197 | 117 | 118 |

*NPK – mineral fertilization; **MBM + K – meat and bone meal with potassium mineral fertilization as in control NPK

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Table 2. Weather conditions in the growing seasons from 2012–2013, and in the 1981–2010 reference period according to the Research Station Bałdy, Poland

| Month | Average air temperatures (°C) | | | Total rainfall (mm) | | |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | 1981–2010 | 2012 | 2013 | 1981–2010 |
| April | 9.1 | 5.9 | 7.7 | 100.0 | 28.5 | 33.3 |
| May | 16.4 | 14.8 | 13.5 | 68.4 | 54.5 | 58.5 |
| June | 17.9 | 17.5 | 16.1 | 105.2 | 61.2 | 80.4 |
| July | 21.6 | 18.0 | 18.7 | 61.8 | 121.9 | 74.2 |
| August | 19.3 | 17.4 | 17.9 | 34.0 | 37.6 | 59.4 |
| Mean | 16.9 | 14.7 | 14.8 | 73.9 | 60.7 | 64.4 |

Temperature and rainfall distribution patterns (excluding the second week of July, which was too wet) were similar to the respective long-term averages, which increased barley yield.

## RESULTS AND DISCUSSION

According to the Central Statistical Office in Poland (2012, 2013), the average grain yield of spring barley of those years reached 3.5 t/ha. In the present two-year experiment, MBM used for spring barley grown for fodder allowed to achieve an average grain yield of 5.3 t/ha (Table 3). In the control treatment with NPK fertilization, grain yield was 4.86 t/ha, and in the treatments without fertilization – 2.07 t/ha. Grain yield increased from 4.51–5.99 t/ha in response to increasing MBM doses. Only the lowest dose of MBM (1.0 t/ha) reduced grain yield by approximately 8%, in comparison with the NPK treatment.

In the experiment 1 t of MBM supplied approximately 79 kg N/ha (Table 1). In comparison with mineral fertilizers (100 kg N/ha), grain yield increased by 0.71 t/ha and 1.13 t/ha in response to the highest two doses of MBM of 2.0 t/ha and 2.5 t/ha, respectively (Table 3). Those two doses supplied high amounts of nitrogen: 158 and 197 kg N/ha, respectively. Research results show that already 1.5 t/ha MBM, i.e. 118 kg N/ha, exerted a yield-forming effect similar to that noted in the control treatment (100 kg N/ha). An increase in MBM dose by 0.5 t/ha (40 kg N/ha) generated average grain yield increase of 0.5 t/ha, but a falling trend was noted: 0.57, 0.47 and 0.42 t/ha grain. Researchers vary in their opinions regarding the optimum dose of MBM fertilizer for spring barley because studies are conducted under different soil and weather conditions, and barley cultivars are characterized by different production potential. In a pot experiment performed by Jeng et al. (2004), an increase in MBM dose from 60–180 kg N/ha led to an over 2.5-fold increase in the grain yield

Table 3. Grain yield and 1000 grain weight (TWG) of spring barley, moisture 15%

| Treatment | Grain yield (t/ha) | | Mean for dose | TWG (g) | | Mean for dose |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | | 2012 | 2013 | |
| O (no fertilizer) | 1.90 | 2.25 | 2.07[a] | 39.57 | 39.50 | 39.54[a] |
| Control NPK | 4.00 | 5.72 | 4.86[bc] | 47.32 | 47.87 | 47.60[b] |
| 1.0 t MBM + K | 3.57 | 5.46 | 4.51[b] | 47.17 | 47.05 | 47.11[b] |
| 1.5 t MBM + K | 4.16 | 6.04 | 5.10[c] | 49.62 | 48.97 | 49.30[b] |
| 2.0 t MBM + K | 4.27 | 6.87 | 5.57[d] | 48.22 | 48.37 | 48.30[b] |
| 2.5 t MBM + K | 4.91 | 7.06 | 5.99[e] | 46.95 | 49.52 | 48.24[b] |
| Mean for year | 3.80[a] | 5.57[b] | – | 46.48 | 46.88 | – |
| d × y | | s | | | ns | |

Values associated with the same letter are not significantly different according to Fischer's test ($P \leq 0.05$). Interaction between meat and bone meal (MBM) dose and year (d × y): s – significant difference; ns – not significant. *NPK – mineral fertilization; **MBM + K – meat and bone meal with potassium mineral fertilization as in control NPK

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of spring barley. However, the best yield-forming effect was observed when nitrogen fertilizer was combined with MBM. In a later study, Jeng et al. (2006) demonstrated that 100 kg N/ha supplied by MBM was a sufficient fertilizer rate for spring barley. In contrast, Svoboda et al. (2010) applied 125 kg N/ha in the form of MBM and achieved an only 8% increase in the grain yield of spring barley. Chen et al. (2011) found that increasing MBM N from 60–120 kg/ha significantly increased barley grain yield. Nogalska et al. (2014) reported that an increase in MBM dose from 1.5 t/ha to 2.5 t/ha had no significant effect on the yields of the four analysed crops, and concluded that in soils with satisfactory nutrient content, MBM dose of 1.0 t/ha or 1.5 t/ha is sufficient, and a further increase in MBM fertilization could increase economic burden for farmers and environmental risks. Spring barley is a crop species with a short growing season and a weak root system, which increases the risk of nitrogen losses to the environment (Shejbalová et al. 2014). Mineral nitrogen, in particular nitrates, pose the greatest risk to the environment. Meat and bone meal contains organic nitrogen that must be mineralized before it is available to plants. Several years' field experiments carried out by Stępień and Wojtkowiak (2015), and Nogalska (2013) point to a low risk of nitrate contamination due to the soil application of MBM. A lysimetric experiment conducted by Jeng and Vagstad (2009) revealed that the amounts of nitrates leached from soil fertilized with MBM were half the quantities leached from soil treated with mineral fertilizers, but the cited authors do not recommend the application of MBM in early spring or late fall since nitrates contained in MBM are easily leached out.

Significant differences in barley grain yield were noted between the years of the study. In the second year, average grain yield was 1.5-fold higher (by 1.77 t/ha) than in the first year, which resulted from more favourable weather conditions in 2013 (Table 2) and the residual effect of MBM. A relationship between spring barley yield and weather conditions was reported also by other authors (Krajewski et al. 2013, Szmigiel et al. 2015). In the present study, the values of TGW were similar (approx. 46.7 g) in both years of the experiment (Table 3). The plumpest kernels (49.30 g) were obtained when MBM was applied at 1.5 t/ha (118 kg N/ha), but the observed differences were not statistically significant. Svoboda et al. (2010) and Chen et al. (2011) also demonstrated that MBM had an insignificant effect on TGW in barley. However, MBM had a beneficial influence on TGW in maize (Nogalska et al. 2012, 2013).

The average nitrogen content of barley grain ranged from 18.64 to 23.79 g/kg DM (Table 4), which corresponded to 116.5–148.7 g/kg DM of total protein, and it was affected by the year of the study and, to a lesser degree, by fertilization levels. The noted values are close to the optimal nitrogen content of barley grown for fodder, recommended by the National Research Institute of Animal Production-INRA (2009), i.e. 119 g/kg DM of total protein. In comparison with the NPK treatment, MBM caused an insignificant (8% on average) decrease in the N content of barley grain. Kernels harvested from control (non-fertilized) plants were characterized by nitrogen deficiency, particularly in the first year of the study. Grain harvested in the second year was more abundant in nitrogen (by 28% on average). This resulted from lower precipitation levels which were comparable with the long-term average. Excessive rainfall is not conducive to protein accumulation in spring barley grain (Szmigiel et al. 2015). Higher nitrogen concentrations in barley grain, noted in the second year of the experiment, could also result from higher supply of nitrogen coming from mineralized animal protein that had not been decomposed in soil in the first year. Stępień and Wojtkowiak (2015) observed a steady increase in protein yield in wheat and rapeseed grain with increasing MBM doses. According to Jeng et al. (2004), nitrogen supplied by MBM satisfies the N requirements of cereals in 80%, and the remainder should be supplied by mineral fertilizers.

The average phosphorus content of spring barley grain varied from 3.96–4.47 g P/kg DM, depending on fertilization levels (Table 4). According to the INRA (2009), fodder barley grain should contain 3.84 g P/kg DM. Phosphorus content noted in this study exceeded the above value, except for the treatment with the highest MBM dose in the second year of the experiment. One ton of MBM per ha supplied 47 kg P/ha (Table 1). The intensive use of MBM (93 and 117 kg P/ha) significantly reduced the P content of barley grain, particularly in the second year of the study, in comparison with the NPK treatment (40 kg P/ha) and treatments with lower MBM doses (47 and 70 kg P/ha) (Table 5). Lower accumulation of P in barley kernels was surprising, and it could result from the dilution effect observed during rapid

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Table 4. Macronutrients content in spring barley (g/kg)

| Treatment | Nitrogen | | Mean for dose | Phosphorus | | Mean for dose |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | | 2012 | 2013 | |
| O (no fertilizer) | 16.24 | 22.11 | 19.17[a] | 4.03 | 3.94 | 3.98[a] |
| Control (NPK) | 19.38 | 26.81 | 23.10[b] | 4.25 | 4.41 | 4.33[b] |
| 1.0 t MBM + K | 19.09 | 23.05 | 21.07[ab] | 4.45 | 4.50 | 4.47[b] |
| 1.5 t MBM + K | 19.28 | 23.18 | 21.23[ab] | 4.38 | 4.51 | 4.45[b] |
| 2.0 t MBM + K | 19.16 | 23.32 | 21.24[ab] | 4.15 | 3.95 | 4.05[a] |
| 2.5 t MBM + K | 18.72 | 24.30 | 21.51[b] | 4.31 | 3.61 | 3.96[a] |
| Mean for year | 18.64[a] | 23.79[b] | – | 4.26 | 4.15 | – |
| d × y | | ns | | | s | |

Values associated with the same letter are not significantly different according to Fischer's test ($P \leq 0.05$). Interaction between meat and bone meal (MBM) dose and year (d × y): s – significant difference; ns – not significant; *NPK – mineral fertilization; **MBM + K – meat and bone meal with potassium mineral fertilization as in control NPK

yield growth. It should be stressed that grain yield achieved in treatments with the highest MBM doses was 2-fold higher (approx. 7.0 t/ha) (Table 3) than the national average. Low MBM doses (1.0 t/ha and 1.5 t/ha) caused a minor (3%) increase in the P content of barley grain, relative to the NPK treatment (Table 4). A positive influence of MBM on P concentrations in barley grain was reported by Haraldsen et al. (2011). In a study by Nogalska and Zalewska (2013), the P content of wheat, triticale and maize fertilized with MBM was similar to that noted in treatments with mineral fertilization, and it was lower in oilseed rape.

Nutrient uptake by crop plants is one of the most important criteria for fertilizer evaluation, and it is estimated based on the biomass produced and the content of a given nutrient in biomass. The highest, statistically significant, nitrogen uptake by barley biomass (166 kg N/ha, dry matter basis) was noted in the treatment with the highest MBM dose (197 kg N/ha), compared with mineral fertilizers (100 kg N/ha) (Table 5). It should be emphasized that the application of a lower MBM dose – 2.0 t/ha (158 kg N/ha) contributed to similar N uptake by barley to that observed in the treatment with mineral fertilization. Jeng et al. (2004) demonstrated that increasing nitrogen doses supplied by MBM from 60–180 kg led to a 3.8-fold increase in N uptake by spring barley. However, this value was significantly lower relative to mineral nitrogen applied in comparable doses. Previous research (Nogalska 2013) shows that cereal crops intensively fertilized with MBM accumulated

Table 5. Uptake nitrogen and phosphorus by spring barley (grain + straw) (kg/ha)

| Treatment | Nitrogen | | Mean for dose | Phosphorus | | Mean for dose |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | | 2012 | 2013 | |
| O (no fertilizer) | 40.10 | 71.53 | 55.81[a] | 10.00 | 15.90 | 12.95[a] |
| Control (NPK) | 87.02 | 203.20 | 145.11[c] | 19.59 | 34.59 | 27.09[bc] |
| 1.0 t MBM + K | 79.90 | 177.85 | 128.88[b] | 20.58 | 33.25 | 26.91[b] |
| 1.5 t MBM + K | 91.21 | 178.91 | 135.06[bc] | 22.65 | 37.59 | 30.12[bcd] |
| 2.0 t MBM + K | 90.92 | 195.86 | 143.39[c] | 22.90 | 37.96 | 30.43[cd] |
| 2.5 t MBM + K | 111.87 | 221.05 | 166.46[d] | 27.09 | 37.76 | 32.43[d] |
| Mean for b | 83.50[a] | 174.73[b] | – | 20.47[a] | 32.84[b] | – |
| d × y | | s | | | ns | |

Values associated with the same letter are not significantly different according to Fischer's test ($P \leq 0.05$). Interaction between meat and bone meal (MBM) dose and year (d × y): s – significant difference; ns – not significant; *NPK – mineral fertilization; **MBM + K – meat and bone meal with potassium mineral fertilization as in control NPK

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significantly more N in comparison with the crops fertilized with mineral nitrogen.

The uptake of phosphorus and nitrogen by spring barley biomass increased gradually in response to increasing MBM doses (Table 5). The positive effect of the highest MBM dose (117 kg P/ha) on P uptake, in comparison with mineral fertilization (40 kg P/ha), was statistically significant. 70 kg P/ha supplied by MBM (1.5 t/ha) increased P uptake by over 11%, compared with soil fertilized with granular triple superphosphate (20.1% P). Nogalska and Zalewska (2013) reported higher P uptake by winter wheat and maize fertilized with MBM relative to plants receiving mineral fertilization. Brod et al. (2012) found no significant differences in P uptake by grasses fertilized with MBM and mineral fertilizers. In the present study, nutrient uptake varied across years. Significantly higher (over 2-fold on average) N uptake by spring barley in the second year of the experiment resulted from higher grain yield and higher N content in plants. Increased P uptake (1.6-fold on average) was related to the barley biomass obtained in the second year.

The results of the two-year field experiment indicate than MBM is a valuable source of N and P for spring barley grown for fodder. Since N and P are biogenic elements which can pose an environmental threat when supplied in large quantities, the maximum dose of MBM applied to barley should not exceed 1.5 t/ha, i.e. approximately 120 kg N and 70 kg P/ha/year. Such a dose is sufficient to produce high yield (5.1 t/ha) of good quality grain with adequate N and P content.

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