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Meat and bone meal as nitrogen fertilizer to cereals in Norway

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Meat and bone meal (MBM) contains appreciable amounts of nitrogen (N), phosphorus and calcium making it interesting as fertilizer to various crops. The effect of Norwegian MBM as N fertilizer has been evaluated in pot and field experiments. The soils used in the pot experiment were peat and a sand/peat mixture, both low in content of plant nutrients. The field experiment was carried out on a silt loam. In the pot experiment increasing amounts of MBM gave significantly increased yields, although there was a partly N immobilisation shortly after seeding the soil based on peat organic matter. In the field experiment there was no period of N immobilisation and good N effect was found also for small amounts of MBM (Total N 50 kg ha^{-1}). At total N 100 kg ha^{-1} there were no significant differences in grain yield of spring wheat between the treatments with MBM, mineral N fertilizer, and combination of MBM and mineral N fertilizer (N 50 kg ha^{-1} from each). The results indicate that the relative N efficiency of MBM compared to mineral fertilizer is 80% or higher, if MBM is applied to cereals in spring.

Key words: fertilizers, meat bone meal, nitrogen use efficiency, organic farming, organic fertilizers, phosphorus

Introduction

Meat and bone meal (MBM) has been widely used as a valuable protein and mineral source in diets of production animals (Hendriks et al. 2002). Development of animal transmissive spongiform encephalopathies (TSE), like ovine scrapie and bovine spongiform encephalopathy (BSE) has been linked to feeding ruminants with MBM contaminated with transmissive agents (Brewer 1999). Therefore the use of MBM to ruminants was banned in the European Union in 1994, and the use of MBM to all production animals was banned in 2000 in the European Union and most other European countries (Kam-

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phues 2002). This situation has forced the meat production industry to look for alternative use of MBM.

The large content of nitrogen (N), phosphorus and calcium in MBM makes it interesting as fertilizer to various crops. The effects of MBM as N fertilizer to wheat were evaluated by Salomonsson et al. (1994, 1995). They found better utilization of N from MBM than from pig slurry, and similar N utilization as urea N. MBM has been found to give sufficient N supply for good baking performance of organically grown wheat (Fredriksson et al. 1997, 1998). Mixing MBM in soil has been found to increase the potato quality, due to reduced incidence of potato scab (*Verticillium dahliae*) and decreased populations of parasitic nematodes (Lazarovits et al. 1999, Lazarovits 2001).

Norway produces about 40,000–45,000 metric tons of MBM annually. Based on the fact that BSE has not been recorded in Norway, minimal import of cattle and no import of meat and bone meal to Norway have been executed, the risk for spread TSE agents in Norway has been found to be negligible (EU commission 2000, Fossum et al. 2001, EFSA 2004). Meat and bone meal is therefore allowed to be used as fertilizer in Norway to all crops, except grassland which are used for grazing or mowing (Norwegian Ministry of Agriculture 2002).

Because most of the N in MBM is organically bound and must be transformed to inorganic N in order to be available for plants, a pot experiment for evaluation of the N fertilizer value was started in 2001, and followed up by a field experiment in 2002. The practical aim of these experiments was to achieve sufficient scientific basis for fertilizer recommendations for MBM.

Material and methods

Analysis of meat and bone meal

Four samples of MBM, representing four different daily productions, were collected from Norsk Protein's destruction factory at Hamar, and analyzed at the laboratory.

pH was determined according to NS-EN 12176. Total contents of phosphorus (P), calcium (Ca) magnesium (Mg), potassium (K), lead (Pb), cadmium (Cd), zinc (Zn) and nickel (Ni) were determined after aqua regia dissolution of the material according to the Norwegian Standard 4770 (NS 4770) by simultaneous ICP-AES, using a Perkin Elmer 3000 DV.

Kjeldahl-nitrogen was determined by the Kjeldahl method (Bremner 1960). NO_3-N and NH_4-N were determined after extraction with 2 M KCl (Henriksen and Selmer-Olsen 1970, Selmer-Olsen 1971) Total organic carbon was determined by combustion of a crushed sample at 925°C using a Perkin Elmer 2400 CHN analyzer, after treatment with 2 M HCl to remove any inorganic carbon.

Readily available P (P-AL) was determined on ICP after extraction with a solution composed of 0.4 M acetic acid and 0.1 M ammonium lactate, buffered to pH 3.75 (Egnér et al. 1960).

Evaluation of fertilizer effects of MBM

The effect of MBM as fertilizer was studied in both the greenhouse and in the field in autumn of 2001 and spring of 2002, respectively.

Pot experiment

The experiment was conducted under greenhouse conditions using constructed growth media [pure peat (Sphagnum) and sand-peat mixture (peat 0.3 m^3 m^{-3})]. The soils were limed with $CaCO_3$, equivalent with 12 Mg ha^{-1} for the peat and 4.5 Mg ha^{-1} for the sand/peat mixture in order to increase the pH to 6.5. At start of the experiment the C/N ratio was 68 in the peat and 20 in the sand/peat mixture. MBM was applied in rates of 0, 760 and 2280 kg ha^{-1}, to give total N applications of 0, 60 and 180 kg ha^{-1}. The highest rate should represent normal N fertilization for grain under greenhouse conditions in Norway. MBM was applied alone or in combination with mineral N in the form of calcium nitrate ($Ca(NO_3)_2$).

Table 1. Combinations of meat and bone meal (MBM) and inorganic fertilizer nitrogen (N) used in the pot experiments in autumn 2001.

Treatments	N in MBM, kg ha^{-1}	N in mineral fertilizer, kg ha^{-1}	Total N applied, kg ha^{-1}
0. No fertilizer	0	0	0
1. MBM_1	60	0	60
2. MBM_2	180	0	180
3. N_1	0	90	90
4. $MBM_{1+}N_1$	60	90	150
5. $MBM_{2+}N_1$	180	90	270
6. N_2	0	180	180
7. $MBM_{1+}N_2$	60	180	240
8. $MBM_{2+}N_2$	180	180	360

Mineral N was given at the rates of 0, 90 and 180 kg ha^{-1}. The total N supply to the different treatments is shown in Table 1. All treatments received a base fertilizer of macro- and micro plant nutrients, based on K_2SO_4 (K 240 kg ha^{-1}, S 90 kg ha^{-1}) and chlorides of Mg, Cu, Zn, Mn and Fe, causing nitrogen to be the growth limiting nutrient. Treatments without MBM were given a P supply of 20 kg or P 40 kg ha^{-1} as $Ca(H_2PO_4)_2$. Treatments with MBM received 0, 20 or 40 kg P ha^{-1}. Because the P supply was sufficient for normal plant growth at each level of N fertilization, the experiment could not be used to quantify the P fertilization potential of MBM. There were three replicates for each of the original treatments. Because the differences in P application gave no yield effects, the treatments with P (20 and 40 kg ha^{-1}) were combined giving six replicates for the N treatments.

Thirty seeds of spring barley (*Hordeum vulgare*, cv. Thule) were sown in the Kick-Brauckman pots in the first week of October. After germination the number of seedlings per pot was thinned to 20. These reached maturity and were harvested in the last week in January. The day temperature was 20˚C and the night temperature was 15˚C. In the period 0800–1600 the light was daylight, while artificial light 10000–15000 Lux was given 1600–0800. An invasion by the Blackberry aphid (*Sitobion avenae*), six weeks before harvest, was treated with the systemic insecticide Croneton.

Field experiment

Experiences from the greenhouse experiments were used to develop the experimental plan for the field experiment. The plan was a randomized complete block design with seven treatments and four replicates (Table 2).

The experiment was located to the Agricultural University of Norway (59˚39'N, 10˚45'E). The soil at the experimental was a poorly drained silt loam (17% clay) of marine origin, which was slightly acidic (pH 6.3). The soil belongs to the

Table 2. Plan for the field experiment.

Treatments	Applied amount MBM, kg ha^{-1}	Applied amount fertilizer, kg ha^{-1}		
		Total N		Total P
		MBM	Min. N	
A. No fertilizer	0	0	0	0
B. MBM_1	630	50	0	35
C. MBM_2	1260	100	0	70
D. MBM_3	2530	200	0	140
E. Mineral N, no P	100	0	100	0
F. No N + mineral P	0	0	0	35
G. MBM_1 + min. N	630	50	50	35

MBM = meat and bone meal

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series Eko6 (Kolkind silt loam above silty clay loam), which has been classified as Stagni-Umbric Albeluvisol according to FAO (1998). The contents of readily available (AL-extractable) P was low (3.5 mg 100 g^{-1} soil), K was medium high (8.5 g 100 g^{-1} soil) and Mg was high (13.5 g 100 g^{-1} soil). This soil normally has relatively large content of non-exchangeable K (K-HNO_3 > 90 mg 100 g^{-1}), which is important for K supply to the plants. Organic C was 2.8 g 100 g^{-1} DM and total N was 0.32 g 100 g^{-1} DM, giving a C/N ratio of nine.

A base fertilization with magnesium sulphate (Mg 15 kg ha^{-1}, S 20 kg ha^{-1}) was applied to all plots. MBM was applied to give N rates of 50, 100, 200 kg ha^{-1} after tilling in early April, in the form of a coarse textured (< 2 mm) powder with a dry matter content of 97%. Even application of the small MBM amounts required for some of the plots was complicated because of the powder form. A commercial mineral N fertilizer (YARA KAS 27) was applied to compare with equal amounts of total N in MBM.

Spring wheat (*Triticum aestivum* cv. Avle) was sown in the second week of April 2002 at a seeding rate of 190 kg ha^{-1}. Herbicide treatment (a mixture containing Storane 400 ml ha^{-1} and Express 15 g ha^{-1}) was undertaken in May, and the plots were harvested in middle of August.

After harvest grain yields were recorded for both the pot and field experiments. Samples of grain from individual treatments were analyzed. N uptake was determined and nitrogen use efficiency (NUE), sometimes referred to as nitrogen recovery, calculated using Equation 1 (Lindén 1997).

$$NUE\ (\%) = 100(X_f - X_0)/X_r\ , \qquad (1)$$

X_f = N yield (kg ha^{-1}) from fertilized plots
X_0 = N yield (kg ha^{-1}) form unfertilized plots
X_r = N application rate (kg ha^{-1}).

For a specific N application rate, the ratio of NUE for applied MBM to NUE for applied mineral N was used as an expression of the relative nitrogen use efficiency (RNUE) compared to mineral nitrogen fertilizer.

Table 3. Chemical characteristics of the Norwegian meat and bone meal used in the experiments.

Parameter, unit	Mean value
pH	6.5
Dry matter (DM), g (100 g)$^{-1}$	97
Loss on ignition, g (100 g)$^{-1}$ DM	66.4
Total organic C, g (100 g)$^{-1}$ DM	29.0
Total N, g (100 g)$^{-1}$ DM	7.89
C/N ratio	3.7
NH_4-N, mg kg^{-1} DM	273
NO_3-N, mg kg^{-1} DM	0.57
Total P, g (100 g)$^{-1}$ DM	5.58
P-AL, g (100 g)$^{-1}$	2.23
N/P ratio	1.4
Total K, g (100 g)$^{-1}$ DM	0.36
Total Ca, g (100 g)$^{-1}$ DM	11.1
Total Mg, g (100 g)$^{-1}$ DM	0.21

Statistical analysis

Analysis of variance (ANOVA) of the data was carried out according to the experimental design for the plot experiment and the field experiment. For multiple comparisons the Tukey's studentized range test (HSD) was used ($\alpha = 0.05$).

Results

Nutrient content in meat and bone meal

Meat and bone meal is weakly acidic (pH 6.5), with an organic matter content of about 50% (calculated from organic C) (Table 3). The Norwegian MBM is a dry powder (97% DM), consisting of particles <2 mm. The content of the plant nutrients Ca, N and P represent approximately 25 g 100 g^{-1}DM, and total nitrogen content is about 8 g 100 g^{-1} DM. The mineral N content (ammonium (NH_4-N) and nitrate (NO_3-N)) represent approximately 3.5% of total N. The C/N ratio of 3.7, however, indicates a large potential for N mineralization.

Total (aqua regia extractable) P was 5.6 g 100 g^{-1} DM. Approximately 40% of this was extractable by the AL-method (Table 3). The concentrations of potassium and magnesium in MBM are low, 0.36 g 100 g^{-1} DM and 0.21 g 100 g^{-1} DM, respectively.

Grain yields

Pot experiments

Increasing amounts of MBM gave significantly increased yields (Table 4). This effect was significant both without extra N-fertilizer (Treatments 1 and 2), and with increasing amounts of mineral N (N_1, Treatments 4 and 5, N_2, Treatments 7 and 8). Application of mineral N-fertilizer caused larger yield response for the largest MBM application (MBM_2) compared to Treatment 2 without added mineral N. The treatments 2, 3 and 4 gave approximately the same grain yields (Table 4). The yield level at Treatments 5 and 6 was not significantly different. The best N-fertilizer response of MBM was found at Treatment 8, which represented the highest levels of MBM and mineral N, and also had the highest yield.

Field experiment

In the field experiment the treatments without N-fertilizer (Treatments A and F) gave small yields (Table 5). The yield obtained by the smallest amount of MBM (MBM_1, 630 kg ha^{-1}, N 50 kg ha^{-1}) was not significantly different from Treatment G, which had received the same amount of MBM and N 50 kg ha^{-1} in mineral fertilizer. There were no statistical significant yield differences ($P < 0.05$) between the treatments where N 100 kg ha^{-1} was applied (Treatments C, E and G). The treatment D with the double amount of MBM compared to Treatment C gave marginal and not significant yield increase for the increased MBM application.

Nitrogen uptake and efficiency

In the pot experiment N uptake increased with N application. The N uptake was greater for mineral N fertilization treatments than for fertilization treatments with MBM. The control removed only about N 3 kg ha^{-1}, emphasizing the poor N status of the soils used in the pot experiment. While the application of N 180 kg ha^{-1} as MBM resulted in yield removal of about N 35 kg ha^{-1},

Table 4. Grain yields as a function of meat and bone meal (MBM) and nitrogen (N) application rates in the greenhouse (values associated with the same letter are not significantly different $\alpha = 0.05$).

Treatments	Nitrogen rate, kg ha^{-1}	Grain yield, kg ha^{-1}		Mean yield, kg ha^{-1}
		Sand-peat mixture	Peat	
0. No fertilizer	0	246	810	528 a
1. MBM_1	60	831	1416	1124 a
2. MBM_2	180	2583	3231	2907 b
3. Min. N_1	90	2124	3054	2589 b
4. Min. N_1 + MBM_1	150	2596	3116	2856 b
5. Min. N_1 + MBM_2	270	5310	6239	5774 c
6. Min. N_2	180	5416	4989	5203 c
7. Min. N_2 + MBM_1	240	6475	8031	7253 d
8. Min. N_2 + MBM_2	360	9276	10635	9955 e

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Table 5. Comparison between meat and bone meal (MBM) and mineral nitrogen (N) fertilizer for N use efficiency in spring wheat grown in a field experiment (values associated with the same letter are not significantly different α = 0.05).

Treatments	Application kg ha^{-1}		Removal kg ha^{-1}		N use efficiency, %
	MBM	Total N	Grain yield	Total N	
A. No fertilizer	0	0	1540 a	31.3 a	
B. MBM_1	630	50	2670 b	52.3 b	42
C. MBM_2	1260	100	3530 cd	70.2 cd	39
D. MBM_3	2530	200	3970 d	81.8 d	25
E. Mineral N, no P	0	100	3690 cd	74.7 cd	43
F. No N + mineral P	0	0	1700 a	34.2 a	–
G. MBM_1 + min. N.	630	100	3180 bc	65.8 bc	35

the same levels applied of mineral N resulted in the removal of twice as much (> N 70 kg ha^{-1}) (Table 6).

In the field experiment increased N uptake with increasing N fertilization was found both for mineral fertilizer and MBM. Application of N 100 kg ha^{-1} gave N-uptake between N 66 and 75 kg ha^{-1}, and there was no significant difference between the N sources mineral N fertilizer, MBM, or mixture with equal amount of total N from mineral N fertilizer and MBM (Table 5).

The N use efficiency was lower for MBM treatments than mineral fertilizer treatments in the pot experiment. The relative nitrogen use efficiency (RNUE) was found to be only 47%. In the field experiment NUE for grain grown on MBM-treated soils (Treatment C) were comparable to that of grain grown on mineral N treated soils (Treatment E). Calculated RNUE was as high as 91% for treatment C. For Treatment G (N 100 kg N ha^{-1}, equal amounts of total N from MBM and mineral N), NUE was somewhat lower than for Treatment C. RNUE for Treatment G was calculated to be 81%, i.e. lower than for MBM alone as N supplier.

Discussion

The differences in N efficiency of MBM in the pot experiment and field experiment may be related to the properties of the growth medium

Table 6. Comparison between meat and bone meal (MBM) and mineral nitrogen (N) fertilizer for N use efficiency in barley grown in sand/peat mixture in greenhouse.

Treatments	N application, kg ha^{-1}	Grain yield, kg ha^{-1}	N uptake, kg ha^{-1}	N use efficiency, %
0. No fertilizer	0	246	2.9 a*	
1. MBM_1	60	831	9.2 b	11
2. MBM_2	180	2583	34.9 d	18
3. Min. N_1	90	2124	28.6 c	29
6. Min. N_2	180	5416	70.6 e	38

* values accompanied by the same letters are not significantly different at α = 0.05

used. In the pot experiment peat and sand/peat mixture were used. These had initially relatively high C/N ratio, 68 and 20 respectively. The field experiment was carried out on a silt loam with C/N-ratio of nine. It is likely that application of smallest amounts of MBM (N 60 kg ha^{-1}) caused a relatively high proportion of the applied N to be immobilised in the peat and sand/peat mixture shortly after seeding. When more mineral N (N 90 or 180 kg ha^{-1}) was applied, this immobilisation of N had less effect on the N uptake. In the field experiment there was no evidence of N immobilisation, and even the smallest amount of MBM showed good N efficiency. The efficiency of MBM in the field experiment was equal or slightly better than that Salomonsson et al. (1994) found for Biofer, which is an organic fertilizer based on meat and bone meal. Salomonsson et al. (1995) found considerably lower NUE values for Biofer than was found for MBM in the present study. The NUE values for MBM found in our field experiment are normal under field conditions using organic fertilizers.

Although almost all the N in MBM is organic, our field experiment show that the RNUE was higher than 80%. Based on 15 field experiments in organic cropped winter wheat Lundström and Lindén (2001) found that the grain yield increase per kg N ha^{-1} was 10 kg grain ha^{-1} for Biofer compared to 39 kg grain ha^{-1} for mineral fertilizer. This indicates a lower N utilization of the MBM-based product than was found in previous Swedish experiments and our field experiment. In experiments with spring wheat and barley, Lundström and Lindén (2001) found very limited yield increase for more than N 40 kg ha^{-1} in Biofer. This was associated with the large supplies of plant-available soil N, partly present in the soil in spring and partly released by mineralization during the growing season.

The differences in N efficiency between the Norwegian MBM and the Swedish MBM-based product, Biofer, may also be due to differences in product form and texture. The Norwegian MBM is a dry powder (particle size < 2 mm), commonly spread using liming equipment. Biofer is in the form of pellets, commonly spread using ordinary fertilizer spreading equipment. As powdered lime and fertilizers often have a more rapid effect than granulated or pelletted products, it is likely that N mineralization will start more rapidly after application of powdered MBM compared to MBM pellets.

Based on representative analyses from Norsk Protein, the mean nutrient content (N–P–K) of Norwegian MBM (8–5–0) represent lower content of N relative to P than the Swedish MBM products (Biofer 10–4–0 and 11–3–0). The narrower N/P ratio (approximately 1.8) is an indication that the applied P will invariably exceed the crop P requirements if MBM is applied to meet the N requirement. Most crop N/P uptake ratios range from 4.5 to 9 (Eghball 1996).

The plant available proportion of P in MBM has not been documented in scientific papers. In the present investigation the treatments with MBM and no extra P fertilizer showed adequate growth limited by the N supply in soils with small amounts of readily available P. Because the P fertilization effects of MBM have not been thoroughly studied, the N fertilization value has so far been found to be of greatest interest for the fertilization practice. The potassium content of MBM is negligible. Unless there is large reserves of K in the soil, K should be supplied when MBM is used as nitrogen fertilizer. In Norway N 100–140 kg ha^{-1} is normally used for cereals. If MBM is used in order to meet the N requirement of the plants, it is recommended to expect 80% of total N as the N fertilizer effect. The implications are that P supplied through the MBM may exceed P crop demands in the first year. Knowledge about the P fertilizer value of MBM is of great interest because i) to high fertilization with P may cause P accumulation in soils and eutrophication of water bodies, and ii) uncontaminated P sources in the world are a limited resource.

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