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Comparison of Bone Products for Phosphorus Availability

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Summary. Three bone products (meat and bone meal, steamed bone meal, and bone chips) were compared to a water-soluble P source (monocalcium phosphate) for P availability and enhancement of tomato shoot growth. All bone products were finely ground to pass through a 40-mesh sieve. The products were added to a phosphorus-deficient greenhouse growing medium based on their P concentration with P at 50, 100, 200, and 400 mg·kg⁻¹. Meat and bone meal produced the least shoot growth in 1992, but all products were similar in 1993. Growth peaked with P at 111 mg·kg⁻¹ in 1992, but in 1993, P at 50 mg·kg⁻¹ was sufficient. Shoot P uptake was in direct proportion to P availability in the soil mix, monocalcium phosphate having the highest shoot P content. Although bone products affected N,

Ca, Zn, and Mn content in shoots, the magnitudes of differences were minor and inconsistent from 1992 to 1993. Major consideration for using a bone product are its relative cost of P, fineness of grind, and CaCO₃ equivalent.

The public's continuing interest in sustainable agriculture and organic food production offers an opportunity for greater use of bone meal or bone manures. This is particularly true in the midwestern United States, where bone products are readily available as by-products of the livestock industry. Bone manures are known to be rich in P, N, Mg, and Ca and are a valued organic fertilizer because of their residual soil P effect and high CaCO₃ equivalency that can reduce soil acidity (Johnson, 1988; Mariakulandai and Manickam, 1975; Paisley, 1960).

Bone products can vary in processing form and in N and P content. For example, steamed bone meal made by boiling or steaming bones at high pressure contains 1% to 2% N and 22% to 30% P₂O₅, of which 50% is citrate

soluble (Mariakulandai and Manickam, 1975). Meat and bone meal made from waste or condemned meat that has been steamed in a special digester to remove fats and to sterilize the product contains ≈6% N and <15% P₂O₅ (Paisley, 1960).

Product nutrient content variability and particle size, as well as soil temperature, soil microorganisms, and soil pH, influence the availability of P for plant growth (Johnson, 1988). Our objective was to compare three commercial bone products against water-soluble monocalcium phosphate [Ca(H₂PO₄)₂·H₂O] for their effectiveness in supplying P. Product effectiveness was evaluated using tomato (*Lycopersicon esculentum* Mill.) shoot growth and P acquisition because tomato is highly responsive to P additions when substrate P is deficient.

Materials and methods

'Pilgrim' tomato seeds were germinated in a 1 peat : 1 perlite (v/v) substrate and transplanted at the second true-leaf stage on 30 Oct. 1992 and 19 Oct. 1993 into 7-inch pots filled with 725 g of a 1 low P soil : 2 peat : 2 perlite (by volume) growing medium with pH adjusted to 5.0 to 6.0 with dolomitic limestone. The growing medium also was amended with NH₄NO₃ and KNO₃ to provide N and K at 100 and 200 mg·kg⁻¹, respectively. The four P sources (source: American Meat Protein Corp., Ames, Iowa) [meat and bone meal, steamed bone meal, bone chips, and monocalcium phosphate at four P rates (50, 100, 200, and 400 mg·kg⁻¹)] were mixed thoroughly with the growing medium using a rotating cement mixer. The monocalcium phosphate was included as a readily water-soluble P source. The products were added to

Table 1. *Selected analysis and fineness of grind of bone products.*

Analysis	Bone product		
	Meat and bone meal	Steamed bone meal	Bone chips
N (%)	8.60	2.60	4.65
P (%)	4.55	11.76	11.08
K (%)	0.41	0.05	0.05
Ca (%)	9.45	24.50	24.00
CaCO ₃ (%)	23.60	61.20	59.90
Mn (ppm)	26	1	<1
Zn (ppm)	114	130	121
Fineness (%) ²	22	13	10

²Percentage of product to pass through a 60-mesh screen. All product materials passed through 40-mesh screen.

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the media to give an equivalent amount of P, based on their P concentration. All treatments, as well as a control, were replicated four times in a factorial, randomized, complete-block design on a greenhouse bench. Analysis of variance and regression statistical

procedures were used to separate treatment differences.

Before transplanting the tomato seedlings, the treated growing medium was incubated for 2 weeks in plastic bags stored at 25 °C to allow the bone products to equilibrate. The

nutrient status of the media were determined by saturated media extract (SME) methods established by the North Central Regional Soil Testing Committee for Greenhouse Soils (Warncke, 1988).

Two weeks after transplanting, all pots received N and K at 200 mg·week⁻¹ in the form of NH₄NO₃ and KNO₃. Root-zone soil moisture was maintained with distilled water on an as-needed basis. This was done by maintaining the pots at field capacity by weighing the pots daily and bringing their weight back to field capacity, ≈1200 g. There was no leaching.

The tomato plants were grown in a greenhouse at 26 °C day/20 °C night (±5 °C) and 50% to 80% relative humidity with natural irradiance supplemented by a combination of metal halide and high-pressure sodium lamps (16 h, 115 μmol·s⁻¹·m⁻²). The experiment was terminated at the appearance of the first flower clusters or at about the nine- to 10-leaf stage of growth on 24 Nov. 1992 and 12 Nov. 1993. The shoots were cut at the soil surface, oven-dried for 72 h at 67 °C, weighed, and ground to pass through a 40-mesh screen. The elemental composition of the shoots was determined by dry-ashing 250 mg shoot tissue and dissolving the ash in a 1:1 HCl (v/v). Phosphorus was determined by the ammonium molybdate colorimetric method. Potassium, Ca, Mg, Mn, and Zn were determined by atomic absorption spectrometry. Total N was analyzed by digesting plant tissue with H₂SO₄ by micro-Kjeldahl procedures.

Results and discussion

Product elemental availability.

Meat and bone meal was ground finer than the other two products, with twice as much passing a 60-mesh screen compared to the other two products (Table 1). However, all products passed a 40-mesh sieve and would be expected to release P similarly. Baker et al. (1989) found that P availability from bone meal is related directly to fineness of grind. They reported a 21% increase in P availability for material ground through a 40-mesh sieve as opposed to a 20-mesh sieve and more uniformity in P release with the finer particle size.

Steamed bone meal and bone chips were similar in P, K, Ca, and CaCO₃ contents (Table 1). Bone chips, however, had almost two times the

Table 2. Initial and final saturated media extract analyses of media amended with bone meal products and monocalcium phosphate averaged across the four P rates²

Analysis	Meat and bone meal	Steamed bone meal	Bone chips	Monocalcium phosphate	Control
1992					
pH					
Initial	5.7 A ^y	5.2 A-C	5.1 BC	4.9 C	5.6 AB
Final	4.5 B	4.7 A	4.5 B	4.6 AB	4.8 A
Soluble salts ^x					
Initial	0.92 A	0.84 A	0.91 A	0.97 A	0.39 B
Final	3.40 A	3.70 A	3.40 A	3.40 A	2.90 A
P (ppm)					
Initial	17 B	23 AB	14 B	48 A	5.0 B
Final	9 A	6 B	4 B	7 AB	0.5 C
Ca (ppm)					
Initial	40 AB	53 AB	54 AB	67 A	29 B
Final	216 A	192 A	228 A	173 A	150 A
Mg (ppm)					
Initial	14 AB	18 AB	22 AB	26 A	8 B
Final	76 A	74 A	84 A	71 A	68 A
1993					
pH					
Initial	6.1 A	5.1 B	4.8 C	4.8 C	5.7 AB
Final	4.8 B	5.0 A	4.6 C	4.7 BC	5.1 A
Soluble salts					
Initial	0.73 AB	0.72 AB	0.76 AB	0.81 A	0.60 B
Final	1.70 A	1.20 B	1.30 B	1.10 B	1.70 A
P (ppm)					
Initial	7 AB	9 AB	8 AB	28 A	3 B
Final	8 A	6 B	4 C	8 A	2 D
Ca (ppm)					
Initial	42 B	54 B	55 B	63 B	98 A
Final	164 A	94 B	100 B	88 B	164 A
Mg (ppm)					
Initial	14 A	16 A	17 A	17 A	16 A
Final	50 A	29 B	29 B	26 B	50 A

²The products were added to the soil media at equivalent P rates based on their P concentration. For P at 100 mg·kg⁻¹, the following quantities of the products were used (in milligrams): meat and bone meal = 2198, steamed bone meal = 850, bone chips = 903, and monocalcium phosphate = 394.

³Means within a row followed by different letters are significantly different at P = 0.05 by Duncan's multiple range test.

^xUnits are dS·m⁻². An acceptable level for seedling growth is 0.75 to 2.0 dS·m⁻².

Table 3. Tomato shoot growth and P content as affected by bone products averaged over P rates from 50 to 400 mg·kg⁻¹ and the control.

P Source	Shoot dry wt (g) ²		Shoot P content (mg)	
	1992	1993	1992	1993
Control	2.00 C ^y	2.12 B	4.4 C	12.3 C
Bone chips	3.52 A	3.27 A	16.5 B	23.1 AB
Monocalcium phosphate	3.28 AB	3.27 A	21.7 A	26.8 A
Steamed bone meal	3.03 AB	3.02 A	16.0 B	21.2 AB
Meat and bone meal	2.67 B	3.20 A	14.8 B	19.5 B

²Harvest was 24 Nov. 1992 (25 d) and 12 Nov. 1993 (24 d) from plants set at the second true-leaf stage of growth in October.

³Means within a column followed by different letters are significantly different at P = 0.05 by the Duncan's multiple range test.

percent N of the steamed bone meal. Meat and bone meal had about two times the percent N of bone chips and three times the percent N of steamed bone meal, but they contained <50% of the P, Ca, and CaCO₃ content of the other two products. Also, meat and bone meal had eight times the percent K and 26 times the Mn content of the other two products. The K and Mn values of all three products were quite low. Zinc was present in all products ranging from 114 to 130 ppm. Other elements were measured, but their concentrations were <1% (Mg and S) or <1 ppm (Na, Cu, B, and Co).

Although differences existed among the bone products' elemental content, the initial soil media SME analysis at transplanting indicated that all the bone meal products provided similar nutrient availability (Table 2). For either year, there were no differences in media NO₃-N or K concentration, averaging 46 and 35 ppm, respectively, due to bone product. Also, soluble-salt levels and Ca and Mg concentrations were similar among all products in both years. Although the meat and bonemeal had the lowest CaCO₃ equivalent (Table 1), the quan-

tity of product added to the growing medium to maintain uniform P concentration was almost three times that of the other bone products, leading to similar media Ca concentrations among the products. The media pH also was highest for meat and bone meal and lowest for monocalcium phosphate and bone chips.

Media P levels increased with increasing P rate (data not shown). However, all bone products initially had less than half the available media P of monocalcium phosphate (Table 2). The initial soil media P concentration of the control were 5.1 and 2.5 ppm for 1992 and 1993, respectively. Available P in the media decreased ≈50% from 1992 to 1993 because the original P concentration in the growing medium was different between the years. However, rate differences were still evident after the media was amended.

Tomato growth. There was no significant product × P rate interaction for shoot growth (as measured by dry weight) for either year. In 1992, meat and bone meal produced the least shoot growth of all amendments (Table 3). In 1993, all products produced similar

shoot growth. For both years, all products increased growth over the control, which was severely P deficient; control shoot dry weight was 2.0 and 2.12 g for 1992 and 1993, respectively.

Increasing the P rate in 1992 to 111 mg·kg⁻¹ growing medium gave maximum shoot dry weight, and further additions depressed yield (Table 4).

Shoot nutrient content. To determine the efficiency of the bone products to supply P, shoot nutrient contents were measured. Shoot P concentration was within 0.22% to 0.54% in 1992 and 0.58% to 0.62% in 1993. The reported sufficiency range for shoot P concentration during the vegetative stages of growth is 0.3% to 0.5% (Marschner, 1995). To avoid growth dilution effects, total shoot P content was used rather than concentration. There was no significant product × rate for shoot P content interaction. For both years, increasing the media P rate from 0 to 400 mg·kg⁻¹ resulted in a significant linear increase ($P < 0.01$) in P shoot content (Table 4). Among the P sources, the water-soluble monocalcium phosphate was superior to all bone products at each P rate, reflecting a higher level of P in the growing medium as indicated by the initial SME P concentration (Tables 2 and 3). The bone products were similar in P uptake both years.

Of the elements that varied by concentration in the bone products, shoot K content was not affected by product or rate either year. Bone product, however, affected N, Ca, Zn, and Mn shoot content (Table 5).

Shoot N content varied with bone product, although ample N was applied uniformly to all treatments as NH₄NO₃. Meat and bone meal contained the highest percent N and the lowest P in the dry product (Table 1). Thus, at the 100-mg P rate, meat and bone meal provided N at 189 mg·kg⁻¹, whereas steamed bone meal provided 22 mg and bone chips provided 42 mg.

Table 4. Tomato shoot growth and P content as affected by media P rate. Values are means of four P sources.

P rate (mg·kg ⁻¹)	Shoot dry wt (mg)		Shoot P content (mg)	
	1992	1993	1992	1993
0	2.00	2.12	4.4	12.3
50	3.02	3.09	10.0	14.4
100	3.50	3.48	15.5	20.8
200	3.15	3.10	20.7	24.2
400	2.82	3.08	23.1	31.1
Significance				
Linear	NS	NS	**	**
Quadratic	**	NS	NS	NS

NS, *, ** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

Table 5. Elemental content of tomato shoots as affected by bone products. Values are means of four P rates.

P source	Shoot dry wt (mg)							
	N		Ca		Zn		Mn	
	1992	1993	1992	1993	1992	1993	1992	1993
Control	110 C ^z	152 B	36 C	87 A	0.16 B	0.28 AB	1.49 A	0.81 B
Bone chips	202 A	210 A	63 A	93 A	0.25 A	0.31 A	1.92 A	1.10 A
Monocalcium phosphate	190 AB	160 B	63 A	75 A	0.22 AB	0.22 B	1.76 A	1.14 A
Steamed bone meal	177 AB	183 AB	56 AB	75 A	0.21 AB	0.27 AB	1.47 A	0.78 B
Meat and bone meal	162 B	192 AB	50 B	73 A	0.16 B	0.31 A	1.49 A	0.40 C

^zMeans within a column followed by different letters are significantly different at $P = 0.05$ by Duncan's multiple range test.

Fig. 1. Growth media P concentrations of various bone products at the termination of the experiment, means of 1992 and 1993 experiment.

Tomato plants grown in meat-and-bone-meal-amended media, however, had the lowest shoot N content of the products in 1992 but had one of the highest shoot N contents in 1993 (Table 5).

The shoot Ca content reflected the Ca concentration in the bone products, bone chips=steamed bone meal>meat and bone meal (Table 5). This was expected, because the Ca concentrations in the bone chips and steamed bone meal products were 39% higher than in the meat and bone meal product (Table 1). This was true for 1992, but not in 1993, when shoot Ca content was the same for all bone products.

Shoots were analyzed for Zn to check the availability of the high amount of Zn found in the products (Table 1). Tomato plants grown in bone chip-amended media had a higher Zn content than plants in meat and bone meal media in 1992. In 1993, tomato plants grown in the two products had equal Zn contents (0.31 mg). Phosphorus rate only affected shoot Zn content in 1992, decreasing linearly ($P<0.02$) with increasing P rate from 0.26 to 0.17 mg. This effect was not evident in 1993.

Shoot Mn content is a reflection of bone product effect on media pH. Meat and bone meal had the lowest

shoot Mn content but also the highest media pH at 6.1 in 1993 (Table 2 and 5). In 1992, there were no differences in shoot Mn content among the products. Media pH for meat and bone meal was lower (5.7).

Final soil medium nutrient availability. Final media SME P concentration in 1992 was <50% of initial P concentration (Table 2). There was a significant interaction between P

source and P rate for growth media P concentration in both years ($P<0.01$). Because values for the 2 years were nearly the same, they were pooled (Fig. 1). The growth media control P concentration was <1 ppm. Meat and bone meal had a significantly higher final P concentration than bone chips or steamed bone meal (Fig. 1 and Table 5). Considering that meat and bone meal produced the lowest shoot dry weight and shoot P content (Table 3), this result was expected.

The Mg and Ca final media concentrations were two to four times higher than the initial values in both years, indicating breakdown of the bone products during the experiment. Meat and bone meal had the highest Ca and Mg levels, reflecting the higher rates applied (two to three times) compared with steamed bone meal and bone chips.

Final media pH dropped from initial levels and was significantly different among the products, but it did not appear to influence P availability in this growth media (Table 2). Weekly additions of N as NH_4NO_3 may have contributed to the reduction of pH in the root zone. During the experiment, meat and bone meal remained within 0.1 to 0.5 pH units of the initial values. Although meat and bone meal had the highest initial media pH, the steamed bone meal medium pH was highest at the end of the experiment. In such

media, P availability and solubility is generally greater within the pH range of 5.0 to 5.5 (Lucas and Davis, 1962; Nelson, 1991). The initial and final media pH were near this range.

The three bone products studied were equally effective in promoting tomato plant growth and P uptake. The differences in product elemental content did not cause differences in shoot growth. There undoubtedly would be differences in performance if the products varied greatly in degree of particle size and application rate. Price of product and amount of product necessary to supply P demand would have to be considered. A lower P-concentration bone product, such as the meat and bone meal, may require high rates to supply the needed P, leading to excessive CaCO_3 , which could be a problem for some crops on near-neutral pH soils.

Literature Cited

- Baker, A.M., J.R. Trimm, and F.J. Sikora. 1989. Availability of phosphorus in bone meal. *J. Assn. Offic. Anal. Chem.* 72:867-869.
- Johnson, P.H. 1988. Building soil with bone meal. *Organic Gardening* 35:30-34.
- Lucas, R.E. and J.F. Davis. 1961. Relationships between pH values of organic soils and availabilities of 12 plant nutrients. *Soil Sci.* 92:177-182.
- Mariakulandai, A. and T.S. Manickam. 1975. Phosphorus and phosphatic fertilizers, p. 114-162. In: *Chemistry of fertilizers and manures*. Asia Publishing House, New York.
- Marschner, H. 1995. Functions of mineral nutrients: Macronutrients, p. 229-300. In: *Mineral nutrition of higher plants*. Academic, London.
- Nelson, P.V. 1991. Fertilization, p. 257-315. In: *Greenhouse operation and management*. Prentice Hall, Englewood Cliffs, N.J.
- Paisley, K. 1960. Organic fertilizers, p. 78-98. In: *Fertilizers and manures*. W.H.L. Collingridge, London.
- Warncke, D. 1988. Recommended test procedure for greenhouse growth media, p. 34-37. In: *Recommended chemical soil test procedures for the north central region*. NCR Publ. 221, North Dakota Agr. Expt. Sta., Fargo.