CHANGES IN SOIL TEST PHOSPHORUS AS A FUNCTION OF INORGANIC AND ORGANIC PHOSPHORUS IN ANIMAL MANURE

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Abstract

Understanding how and why soil test phosphorus (P) levels increase with manure and fertilizer application is important to assist in improving any nutrient management plan. An incubation study investigated the change in soil test P (STP) after 42 different animal manures (dairy, beef, swine, chicken, turkey, goat, sheep, and horse) or fertilizer were applied at a rate of 40 mg total P kg^{-1} to 25 different agriculturally important soils of Wisconsin. Both liquid and solid dairy and swine manure were represented, while only solid manures were included for the other species. Total P in animal manure ranged between 2.8 and 48.7 g P kg^{-1}, dry matter basis. Initial STP ranged between 14 and 69 mg P kg^{-1}. Treated soils were incubated for 10 weeks at 60% of water filled pore space at 25°C. After incubation, soils were extracted in Bray P-1. There were significant interactions between P sources and soil series, indicating that each manure changed STP differently when applied to different soils. The change in STP for the fertilizer treatment ranged between 13 to 36 mg P kg^{-1}. Liquid swine manure increased STP as much as or more than fertilizer, while solid swine manure increased STP less than or equal to fertilizer. Unlike swine manure, both solid and liquid dairy manure increased STP similarly to each other and less than or equal to fertilizer. To further investigate the reasons for the results observed, enzymatic hydrolysis of organic P and chemical speciation of inorganic P fractions in the manures are being conducted.

Introduction

Manure has proven to be an important source of nutrients for crop production, but nutrients and pathogens from manure can cause environmental problems during and after land application. Animal manure applied to soil can change soil test phosphorus (STP) differently than commercial sources of fertilizer. The changes in STP when manure is used as a phosphorus (P) source have been reported to range from less available to more available when compared with P from commercial fertilizers (Siddique and Robinson, 2003). In addition, different changes in STP are found when the same manure is applied to different soils (Maguire et al., 2004). These diverging results are thought to be mainly a result of the different mechanisms and strength of chemical bonds between soil and P from manure and fertilizer (Holford et al., 1997). It has been reported that certain organic compounds in manure have a higher capacity to break down soil minerals, such as aluminum and iron silicates, creating biding sites in the soil (Appelt et al., 1975). The newly created binding sites might be responsible for increasing manure P sorption onto the soil. However, the mechanisms and organic compounds involved in such chemical reactions are yet to be well understood.

Some of the differences between soil with regard to how much STP changes after manure application might also be a result of the different forms of P in manure. Phosphorus in manure can be found in two different forms: inorganic P (P_i) and organic P (P_o) in a hydrolysable form as well as in a non-hydrolysable form. The non-hydrolysable P (P_n) is also referred to as residual P. The P_i is mainly composed of Ca-phosphate and in some cases struvite minerals (Ajiboye et al., 2007). The P_o can be divided into phytic acid, monoester, and DNA-like P among other organic forms (He et al., 2004). The P_n is the fraction considered not available for plant or microbe uptake. When manure is applied to soils, the P_i fraction is bioavailable and behaves similarly to inorganic fertilizer, whereas the P_o fraction requires microbial decomposition to liberate P_i into solution. This may explain some of the differences in P availability when manure is compared with inorganic sources of fertilizer but interactions of P_i, P_o, and other compounds in manure likely influence the amount of manure P that is sorbed to soil (becomes bioavailable). For example, Marshall and Laboski (2005) reported greater sorption of P_i from dairy slurry compared to fertilizer and observed dissolution of Fe and Al from soil during 24 h of equilibrating dilute dairy slurry with soil. In contrast, they reported preferential sorption of P_o from swine slurry with no evidence of Fe and Al dissolution during equilibration.

The objectives of this study were to assess the change in extractable soil P after manure application and to determine the relative effectiveness (RE) of different manure types on increasing soil test phosphorus (STP) compared with fertilizer triple superphosphate (TSP).

Material and Methods

Soil Selection, Sampling, and Chemical Properties

Twenty-five different soil series collected throughout Wisconsin, representing the five major mineral soil groups (A – E, which are defined by pedogenesis (Laboski et al., 2006)), were used in this study. Five soils series from each soil group were sampled. Soil samples were collected from each site to a depth of 15 cm. The soils were air-dried and sieved to pass through a 5 mm sieve. Sieved soil samples were stored in air-tight containers until the start of the study. The samples used in the chemical analysis were air-dried and ground to pass through a 2 mm sieve. Soil pH was measured in water (1:1 ratio w/w) and organic matter (OM) content was measured by loss on ignition. Extractable P was measured in the Bray P-1 extractant. Phosphorus along with Al and Fe, were also extracted using ammonium oxalate and Mehlich-3 extractants and determined by ICP-AES. All procedures were conducted as described by Denning et al. (1998) except ammonium oxalate, which was described by Pote et al. (1999). The phosphorus saturation index (PSI) was calculated as ammonium oxalate extracted P (mmol kg^{-1}) divided by the sum of ammonium oxalate extracted Al and Fe multiplied by 100 (mmol kg^{-1}) = ([P] / [Al + Fe]) * 100 (Pote et al., 1999). Soil characteristics are provided in Table 1.

Manure Collection and Chemical Analysis

The 42 manure samples collected from Wisconsin farms include 18 dairy (liquid, slurry, semi-solid, and solid), eight beef (solid), four swine (liquid and solid), three of chicken and turkey (solid), and two each of sheep, goat, and horse (solid). Manure types were separated based on dry matter content where 0 to 3.9% is liquid, 4 to 10.9% is slurry, 11 to 19.9% is semisolid, and 20 to 100% is solid. Dairy manure represents the largest number of samples because it is the largest manure source in Wisconsin. The manure samples were frozen (-20°C) within a few hours after collection to assure that manure chemistry did not change considerably from the time of sampling. Manure samples were analyzed for total P (dry ash method), total N (by digestion), dry matter (DM) content, pH, and electrical conductivity (EC) as described by Peters and Combs, 2003 (Table 2).

Incubation Study Set up

For each soil, the required amount of each wet manure or TSP to provide 40 mg P kg^{-1} (180 kg P_2O_5 ha^{-1}) was weighed into 70 ml specimen cups containing 50 g of soil and was thoroughly mixed. For the control, no manure or TSP was added to the soil. Each treatment was replicated four times and each specimen cup was covered with a perforated cover to allow for air exchange. Samples were incubated at 25°C for 10 weeks, with soil moisture content kept in the rage of 40 to 60% of field capacity. Samples were weighed on a weekly basis and deionized water was added as required. After 10 weeks, samples were removed from the incubator and oven-dried at 35°C for 48 hours. Dried samples were ground to pass through a 2 mm sieve. Soil test phosphorus was measured with the Bray P-1 extractant. The change in STP was calculated by subtracting the STP in the control from STP in each treated soil. The relative effectiveness (RE) of manure to increase STP compared to fertilizer was calculated by dividing the change in STP from manure by the change in STP from TSP for each soil and multiplying by 100.

Statistical Analysis

The change in STP and RE values were analyzed by analysis of variance, ANOVA, using Proc Mixed package in the SAS software (SAS Institute, 2004). Stepwise regression analysis was performed using the stepAIC algorithm from the library(MASS) package in the R software (R, 2007).

Results and Discussion

Initial P Status in Soil and Manure

There was a wide range in STP for the soils used in this study (Table 1). Bray P-1 ranged from 14 to 69 mg P kg^{-1}, Mehlich-3 ranged from 25 to 103 mg kg^{-1}, and ammonium oxalate P ranged from 130 to 571 mg kg^{-1}. The PSI has been used as a tool to help identify soils with increased potential to contaminate water bodies (Pote et al., 1999). Although some researchers have found strong correlations between PSI and STP, there were only weak correlations between PSI and initial STP measured with the three soil extractants in this study. The correlations of PSI with STP were 0.48, 0.59, and 0.35 for Bray P-1, Mehlich-3, and ammonium oxalate, respectively.

The manure samples varied greatly between animal species with regard to dry matter content (DM), total N, total P, EC, and pH (Table 2). Total P within animal species was similar to concentrations reported by other researchers. There were no correlations between manure DM and total P for beef, dairy, or swine manure. For the other animal species no correlation was determined because there were only two or three samples for each species.

Effects of Fertilizer on Soil Test Phosphorus

When averaged over soil group, increase in STP with TSP was greater for coarse-textured soils (group E) than for the medium- and fine-textured soils (groups A – D) (Table 3). There were significant differences between soil series within groups A and D, but not for the other three groups. For soils in group A, TSP application increased STP significantly more on the Billet soil (26 mg kg^{-1}) compared to Waymor low (20 mg kg^{-1}), St. Charles (18 mg kg^{-1}) or Fayette (14 mg kg^{-1}) soils. The increase in STP for the Fayette soil was significantly less than Waymor high (23 mg kg^{-1}). For group D, TSP application increased STP by 24, 25, and 24 mg P kg^{-1} on Antigo, Freeon, and Rosholt soils, respectively; these STP increases were significantly greater than the increased STP observed for Loyal and Withee soils (15 and 17 mg P kg^{-1}, respectively). Stepwise regression was performed in an attempt to try to understand these significant differences within and among soil groups. In this regression analysis, soil chemical and physical characteristics reported in Table 1 were correlated with the change in STP from each soil. The results of the Stepwise analysis showed that change in STP was very weakly (R^2= 0.39) correlated with OM and Fe in a two parameter model. In addition the analysis showed that soil pH, initial Bray P-1, Mehlich-3 P and Al, sand, silt, clay, and PSI were not significantly correlated to the change in STP after TSP was applied.

Effects of Animal Manure on Soil Test Phosphorus

The soil groups used in the study behaved differently when manure from different animal species were applied, which resulted in a significant soil by animal species interaction. Overall soils from group E had the largest increase in STP, regardless of animal species (Table 3). Soils from groups A and C were usually intermediate, and soils from groups B and D had the smallest increase in STP (Table 3). In general, these results agree with those found for the fertilizer treatment; but there were exceptions. For example, the change in STP in groups B and C were the same after beef manure application, while the change in STP for group C was greater than B after goat or dairy manure application. Within animal species, swine had the greatest increase in STP, chicken was the second, and beef and dairy increased STP the least (Table 3). In all soils swine manure increased STP significantly more than the TSP treatment, while all other manures increased STP significantly less than STP in all soils, except for chicken manure applied to group C soils which resulted in an increase in STP equal to TSP.

Table 3 shows the average increase in STP for each soil group when P from different animal species or fertilizer is applied. However, when manures were separated into dry matter class, liquid swine manure increased STP more than solid swine manure for all soil groups (Table 4). In addition, 22.5% more P was recovered (49 mg P kg^{-1}) on average than was applied (40 mg P kg^{-1}) for group E soils (Table 4). This suggests that liquid swine manure desorbed P_i (made more P_i available) from the soil. A similar trend was observed for the dairy manures, where manures with lower dry matter contents increased STP more than manures with high dry matter contents. In general, when manure was applied, soils from group E had the greatest increase in STP followed by groups A and C, and groups B and D.

Stepwise regression was also performed to try to understand the significant interaction between soil group and animal species. In this type of regression analysis, both soil and manure characteristics (Tables 1 and 2) were used in an effort to explain the changes in STP after manure application. No soil or manure properties measured thus far have been significantly related to the increase in STP.

The RE of manure to increase STP compared with fertilizer also differed among the soil groups and animal species, resulting in a significant soil group by animal species interaction (Table 5). Soils from groups C and E had the greatest RE. The RE values for soil group D were the lowest, and those from soil group A and B were intermediate (Table 5). However, within each soil group, the results were very similar to those observed for the change in STP. For example, swine had the greatest RE, followed by chicken, whereas, beef and dairy had the lowest RE (Table 5).

Within a soil group, the RE of a manure source to increase STP varied with soil series; examples are provided for group C and D soils in Figures 1 and 2, respectively. The most striking result is that liquid swine manure always resulted in RE values greater than 100%, for all soils in all groups except for the Kewaunee soil (group C). For group C soils (Figure 1), the RE for all manures except dairy and beef was greater when manure was applied to Emmet, Hortonville High, and Hortonville Low soils compared to Kewaunee and Manawa soils. For the dairy manures and to some extent the beef manure, the RE effectiveness when manure was applied to the Emmet soils was more similar to the RE of the Kewaunee and Manawa soils.
For group D soils, dairy liquid or diary slurry applied to the Freeon soils resulted in a larger RE compared to the other soils (Figure 2). When diary semi-solid or solid manure or beef manure were applied to these soils RE was more similar across soil series. Manures other than dairy or beef generally had a greater RE which was more variable across soils in group D.

Enzymatic hydrolysis has been used to identify forms of organic P in manure that can easily be converted to inorganic P (He et al., 2004). Perhaps, the key to understanding changes in STP after manure application and the RE of manure to increase STP compared to TSP lies in knowing the forms of organic P in the manure. Currently organic P forms are being determined for the manures in this study.

Conclusion

The increase in STP with manure application varied with both animal species and soil series. It is not possible to explain the results with the soil and manure characteristics measured to date. Knowing the forms of P in manure might be useful in interpreting the interaction between soils and manures with regard to how much STP increases with manure application. The results do suggest that assuming all manures and fertilizer increase STP the same amount on all medium- and fine-textured soils or all coarse-textured soils is incorrect. Having a more precise understanding of changes in STP with manure application will be useful for nutrient management planning.

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Table 1. Selected soil chemical and physical characteristics for soils from group A through E used in the incubation study.

Group	Soil	pH	OM	Bray	Mehlich-3			Sand	Silt	Clay	PSI[†]
				P	P	Fe	Al				
			(%)	mg kg^{-1}				%			
A	Billet	6.4	2.6	17	86	153	692	70.5	26.0	3.5	15.6
A	Fayette	6.9	2.7	14	25	100	403	22.5	64.0	13.5	9.0
A	St Charles	6.7	3.4	64	92	141	455	57.9	33.0	9.1	19.9
A	Waymor High	7.1	4.2	61	98	132	528	52.2	40.0	7.8	18.1
A	Waymor Low	6.6	2.9	30	55	199	527	48.9	40.0	11.1	12.9
B	Dodgeville	5.7	3.4	18	41	134	679	18.2	66.0	15.8	10.6
B	Hochhein	6.8	3.0	37	91	120	428	36.2	54.0	9.8	16.3
B	Pella	7.7	5.6	56	103	301	250	26.4	51.0	22.6	23.3
B	Plano	6.8	3.7	26	55	106	618	17.9	67.0	15.1	13.2
B	Ringwood	5.5	3.6	27	59	156	739	24.2	63.0	12.8	13.0
C	Emmet	7.2	3.9	30	55	152	552	70.2	26.0	3.8	12.0
C	Hortonville High	6.9	2.9	43	80	118	397	17.9	70.0	12.1	17.0
C	Hortonville Low	7.1	2.6	15	46	114	433	58.5	34.0	7.5	13.8
C	Kewanee	7.7	3.6	14	32	196	538	45.9	40.0	14.1	12.6
C	Manawa	8.1	3.3	14	33	116	296	31.2	46.0	22.8	16.1
D	Antigo	5.6	3.4	24	51	161	1017	55.9	41.0	3.1	9.6
D	Freeon	7.0	3.3	69	99	152	518	25.9	67.0	7.1	17.1
D	Loyal	6.4	4.1	26	53	161	608	30.9	62.0	7.1	13.6
D	Rosholt	6.9	1.3	15	36	79	393	77.4	14.0	8.6	14.2
D	Withee	6.5	3.0	23	40	150	777	27.9	63.0	9.1	9.7
E	Chetek	5.3	1.7	37	68	133	617	73.4	20.0	6.6	16.7
E	Mahtomedi	6.7	1.5	16	45	75	386	87.9	9.0	3.1	12.9
E	Menominee	6.8	1.8	29	47	98	466	78.9	16.0	5.1	13.7
E	Plainfield	5.6	1.3	53	98	122	684	87.9	7.0	5.1	16.4
E	Richford	6.0	1.5	40	70	97	594	90.9	4.0	5.1	14.4

[†] PSI, Phosphorus saturation index.

Table 2. Range of selected chemical and physical characteristics of animal manure by species.

Species	Number of samples	DM[†]	Total N	Total P	Total K	EC	pH
		(%)	g kg^{-1} DM			$dS\ m^{-1}$	
Beef	8	27.0 – 62.3	14 – 36	4.5 – 14.2	1.3 – 3.9	2.6 – 6.6	6.5 – 8.6
Dairy	18	0.8 – 54.7	15 – 142	2.8 – 18.7	1.0 – 12.0	2.2 – 12.8	6.4 – 10.3
Goat	2	31.1 – 31.3	31 – 36	10.3 – 13.1	3.3 – 3.4	5.9 – 8.1	7.5 – 7.9
Sheep	2	37.4 – 39.7	19 – 29	7.2 – 10.7	1.9 – 2.9	3.6 – 5.3	7.9 – 9.0
Swine	4	0.1 – 30.3	31 – 408	24.1 – 48.7	1.8 – 7.8	3.0 – 13.7	6.1 – 7.9
Chicken	3	26.3 – 94.1	41 – 51	17.7 – 23.9	2.8 – 3.1	10.3 – 15.2	6.1 – 7.0
Turkey	3	57.7 – 85.6	34 – 51	11.3 – 28.2	1.7 – 2.6	4.5 – 12.3	5.5 – 5.9
Horse	2	30.8 – 89.9	16 – 17	5.4 – 12.4	1.2 – 1.9	1.4 – 2.0	7.2 – 9.0

[†] Dry matter (DM), Total nitrogen (Total N), total phosphorus (Total P), Total potassium (Total K), Electrical conductivity (EC), and pH.

Table 3. Change in soil test phosphorus in each soil group as a function of P source.

P Source	Soil Group														
	A			B			C			D			E		
	Change in STP mg kg^{-1}														
Beef	10	f[†]	B	10	d	BC	10	f	C	9	e	C	16	h	A
Dairy	10	f	C	8	e	E	11	e	B	8	f	D	18	g	A
Goat	15	d	B	10	d	E	14	c	C	11	d	D	20	e	A
Sheep	14	e	B	12	c	C	14	c	B	11	d	C	22	d	A
TSP	21	b[†]	B	17	b	C	17	b	C	21	b	B	26	b	A
Swine	25	a	B	21	a	D	24	a	B	23	a	C	36	a	A
Chicken	17	c	B	13	c	D	16	b	C	15	c	C	24	c	A
Turkey	13	e	B	9	d	D	13	d	B	11	d	C	19	ef	A
Horse	13	e	B	10	d	D	12	d	B	11	d	C	18	fg	A

[†] Means followed by the same lower case letter in a column, or uppercase letter in a row are not significantly different (*P = 0.05*).

Table 4. Change in soil test phosphorus in each soil group as a function of fertilizer (TSP) and swine and dairy manure.

Species	Form[¶]	Soil Group A			B			C			D			E		
		Increase in STP mg kg^{-1}														
Dairy	Liquid	13	d[†]	B	10	d	C	13	d	B	10	d	C	22	cd	A
Dairy	Slurry	11	e	B	7	e	D	11	e	B	10	d	C	20	d	A
Dairy	Semi Solid	9	f	B	7	e	C	10	f	B	7	e	C	14	f	A
Dairy	Solid	9	f	B	7	e	C	10	f	B	7	e	C	17	e	A
TSP	Solid	21	b	B	17	b	C	17	b	C	21	b	B	26	b	A
Swine	Liquid	33	a	B	31	a	C	33	a	BC	32	a	BC	49	a	A
Swine	Solid	16	c	B	11	c	D	15	c	B	13	c	C	23	c	A

[¶] Liquid, 0-4% dry matter (DM); slurry, 4-11% DM; semisolid, 11-20% DM; solid, 20-100% DM.
[†] Means followed by the same lower case letter in a column, or uppercase letter in a row are not significantly different (*P = 0.05)*.

Table 5. Relative effectiveness of manure to increase soil test phosphorus compared with fertilizer in each soil group.

Species	Soil Group A			B			C			D			E		
	RE (%)														
Beef	49	e[†]	C	59	cd	B	57	f	B	46	d	D	63	g	A
Dairy	50	e	C	46	e	D	63	e	B	38	e	E	70	f	A
Goat	77	c	B	59	c	C	85	c	A	51	c	D	76	d	B
Sheep	70	d	B	74	b	B	86	c	A	52	c	C	84	c	A
Swine	122	a	D	130	a	C	145	a	A	105	a	E	141	a	B
Chicken	89	b	B	76	b	C	97	b	A	71	b	D	94	b	A
Turkey	67	d	B	56	d	C	77	d	A	52	c	C	74	de	A
Horse	68	d	B	61	c	C	74	d	A	48	cd	D	71	ef	A

[†] Means followed by the same lower case letter in a column, or uppercase letter in a row are not significantly different (*P = 0.05)*.

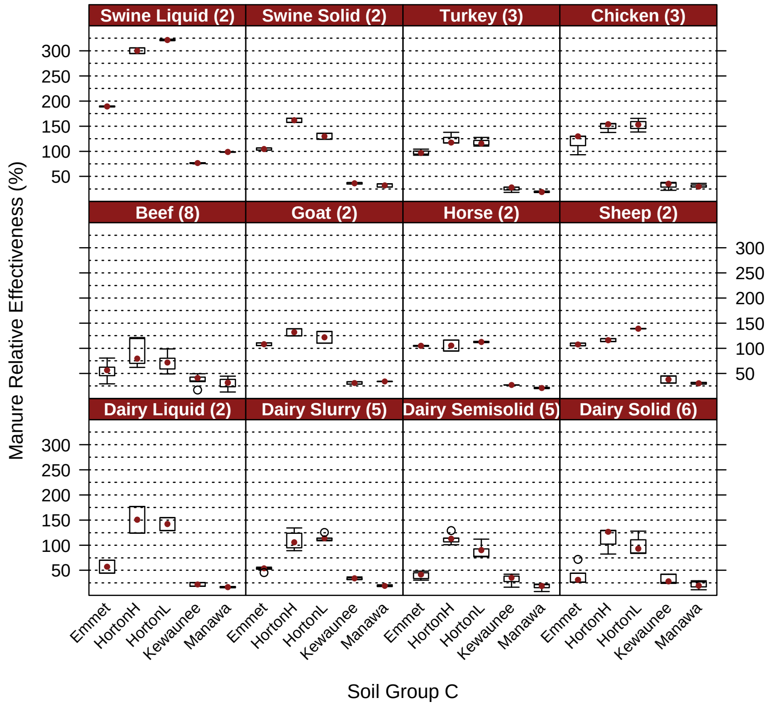

Figure 1. Relative effectiveness of manure to increase STP compared with fertilizer in each soil series from soil group C. Number within parentheses indicates number of samples in each manure/dry matter group.

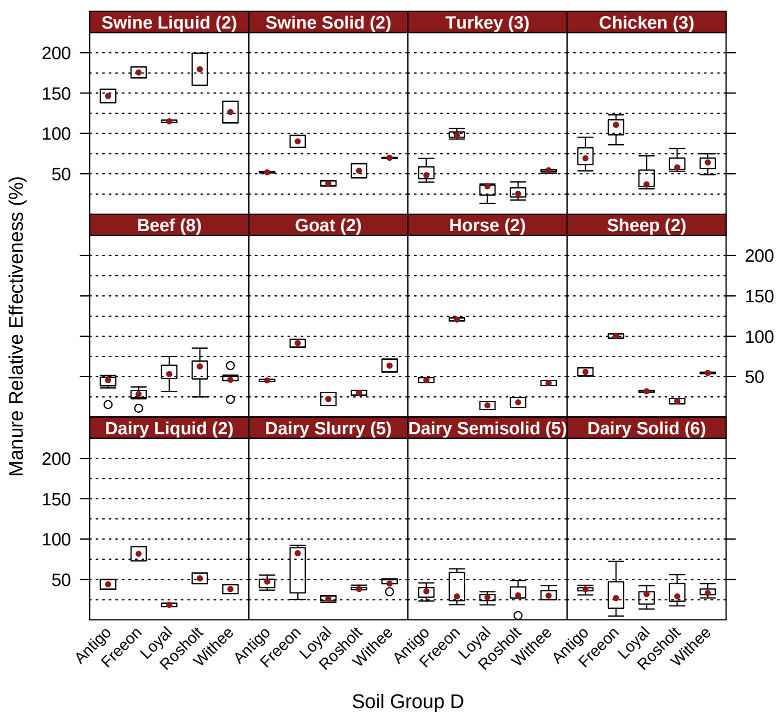

Figure 2. Manure relative effectiveness to change STP compared with fertilizer in each soil series from soil group D. Number within parentheses indicates number of samples in each manure/dry matter group.

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