Soil Microorganisms And Crop Yields After Cattle Manure, Hog Manure Or Fertilizer Application

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Abstract

Soil biological properties can be significantly impacted by land management. Cattle manure, hog manure or inorganic fertilizers were applied annually or triennially to a Gray Wooded soil at Falher, Alberta, over three years. A control treatment without manure or fertilizer was also included. Canola (*Brassica napus*) was grown in Year 1, hulless barley (*Hordeum vulgare*) in Year 2, and wheat (*Triticum aestivum*) in Year 3. Where effects were significant, cattle manure increased soil microbial biomass C (MBC) by 26-86%, hog manure by 31%, and inorganic fertilizers reduced MBC by 20%. Similar effects, except the reduction by inorganic fertilizers, were observed for functional diversity of soil bacteria (Shannon index, H'). Crop N uptake from hog manure was higher than that in other treatments in Year 1, when hog manure increased grain yields by 75%, cattle manure by 49%, and inorganic fertilizers had no significant effect. However, cattle manure out-yielded other treatments in Years 2 and 3 (25-50% increase over the control) even though N uptake from inorganic fertilizers was the highest in Year 2. This implies that factors other than nutrient uptake also influenced crop yields. Frequency of application usually had no effects on MBC or H', but the triennial application rate of inorganic fertilizers reduced crop yields relative to annual applications in Year 1.

Introduction

Land management practices have a significant impact on soil biological and biochemical properties, usually through increase or depletion of soil organic matter. Application of manure to farm land increases soil organic matter, which increases nutrient availability (Stevenson et al. 1998; Hao and Chang 2002; Mooleki et al. 2002) and improves soil physical properties like structure, aeration, drainage and water holding capacity (Whalen and Chang 2002; Miller et al. 2002; Reynolds et al. 2003). Mineralization of biodegradable C contained in applied manure also alters soil ecology. Rochette and Gregorich (1998) reported 2- to 3-fold increases in soil respiration and MBC after three years of manure application. Lalande et al. (2003) reported that application of 11.5 t ha^{-1} of co-composted papermill sludge and hog manure increased soil enzyme activity by 30% and MBC by 55%. Peacock et al. (2001) observed that Gram-negative bacteria increased by 15-27% with dairy manure treatments, but decreased by 15% with ammonium nitrate treatments, compared with control treatments. Marschner et al. (2003) and

Parham, et al. (2003) found that manure promoted bacterial growth more than fungal growth in soils. It has been hypothesized that the effect of manure on soil microbial communities is similar to the rhizosphere effect due to high levels of soluble organic C which support high levels of microbial activity in both cases (Peacock et al. 2001).

The alteration of the composition and activities of soil microbial communities by manure is important for crop nutrition and health. Manure supplies both macro- and micro-nutrients (Stevenson et al. 1998; Hao and Chang 2002) . Most of the N and P contained in manures is in organic forms, which are not available to plants. Soil microorganisms mineralize these nutrients into inorganic forms that plants can utilize. However, manure application rates based on crop N requirements can result in soil accumulation and runoff of P because manure N/P ratio is usually smaller than crop N/P uptake ratio (Eghball and Power 1999). With regard to crop health, crops grown on soils with high organic matter and active soil microorganisms tend to be less infested with weeds (Kremer and Li 2003), diseases (Bailey and Lazarovits 2003) and insect pests (Altieri and Nicholls 2003). Contrary to the belief that animal manures increase the incidence of common scab disease of potatoes (Bailey and Lazarovits 2003), Conn and Lazarovits (1999) found reduced incidences of wilt, common scab and a number of plant-parasitic nematodes for three years after a single manure application. The mechanisms of disease control by N-rich organic manures include release of allelochemicals generated during manure storage or subsequent decomposition, and stimulation of microorganisms with bio-control properties (Lazarovits 2001; Bailey and Lazarovits 2003).

The objective of this work was to investigate changes in soil MBC, functional diversity of bacteria, and crop yields after application of cattle manure, hog manure and inorganic fertilizers in Gray Luvisolic soils of northern Alberta.

Methodology

In field experiments conducted at a low inorganic-N site at Falher, Alberta, cattle (*Bos taurus*) manure (solid), hog (*Sus domesticus*) manure (liquid) or inorganic fertilizers were applied to meet crop N requirements according to soil test recommendations. A control treatment without organic manure or inorganic fertilizer treatment was also included. The nutrient sources were applied either annually or triennially, i.e., as a one-time application (in Year 1) of a projected 3-year N requirement. The two factors (nutrient source and application frequency) were arranged factorially in a randomized complete block design (RCBD) with four replications. The trial was conducted from 2000 to 2002. The soil was Gray Luvisolic with the following characteristics (0-15 cm depth) before treatments were established: pH (1:1 soil:water) 6.8, 15.5 g organic C, 17.3 mg NO_3-N, 8.0 mg PO_4-P and 17.0 mg SO_4-S per kg soil. Soil PO_4-P was extracted with $CH_3COOH + NH_4F$ and the available P was considered as low. Sulphate-S was extracted with $CaCl_2$ and the soil had adequate S.

The nutrient contents of the manures at the time of application are listed in Table 1. The bedding for cattle manure was wheat straw. The triennial application rate for cattle manure in Year 1 was 111 t/ha, and annual applications were 17, 37 and 30 t/ha. The corresponding rates for liquid hog manure were 157 m^3/ha triennial rate, and annual applications were 45, 56 and 26 m^3/ha in Years 1 to 3. Manures were broadcast on the soil surface and disced into soil at 15 cm depth within 24 h. The N from inorganic fertilizer was side-banded as urea (46-0-0 N-P_2O_5-K_2O) to supply 263 kg N/ha triennially, and annual applications were 39, 90 and 62 kg N/ha in

Years 1, 2 and 3, respectively. In the fertilizer treatments, phosphorus and potassium were applied (seed-placed) as a blend of ammonium phosphate (12-51-0) and potassium chloride (0-0-60) according to soil test recommendations, and the N in ammonium phosphate was accounted for when applying urea. These P and K fertilizers were applied only at annual rates, only in fertilizer treatments. Triennial application rates were greater than the sum of the corresponding three annual rates because triennial rates were based on Year 1 soil analysis, but subsequent annual rates were adjusted according to soil analysis results in each year.

Table 1. Characteristics (on wet weight basis) of cattle and hog manures applied.

Manure property	Year 1		Year 2		Year 3	
	Cattle	Hog	Cattle	Hog	Cattle	Hog
DM (g/kg or L)[z]	316.5	37.2	n.d.[y]	n.d.	n.d.	n.d
Total N[x] (g/kg or L)	7.4	4.6	10.7	2.6	8.5	2.7
Organic N (g/kg or L)	7.4	1.3	n.d.	n.d.	n.d.	n.d
NH_4-N[w] (g/kg or L)	0.067	3.3	n.d.	1.3	n.d.	1.5
NO_3-N[w] (g/kg or L)	0.007	0.007	n.d.	n.d.	n.d.	n.d
Total P[x] (g/kg or L)	1.5	1.0	1.4	0.2	1.3	0.1
Total K[x] (g /g or L)	7.8	2.0	5.8	0.1	5.4	1.2

[z]g/kg for solid cattle manure and g/L for liquid hog manure.
[y]n.d. = not determined.
[x]Digested with $H_2SO_4 + H_2O_2$ (Thomas et al. 1967).
[w]Water-extractable.

Canola was grown in Year 1, hulless barley in Year 2, and wheat in Year 3, all under zero tillage except for the discing-in of manures. The crops were seeded about a week after manure application, but fertilizers were applied at seeding time. Glyphosate was applied as a pre-seeding burn-off, and in-crop herbicides were applied according to weed spectra.

At flowering stage of canola, and flag-leaf stage of barley and wheat, soil samples were collected between crop rows to 7.5 cm depth from four different locations per plot. This soil is here-in called bulk soil. In 2002, rhizosphere soil was also sampled by excavating plants from 0.5 m row length at four different locations in a plot, shaking off loose soil, and carefully collecting (by brushing) soil adhering to plant roots. The soil was sieved through a 2 mm sieve and stored at 4 ^{o}C until required for analysis, typically within a month.

Soil MBC was measured using the substrate-induced respiration (SIR) method (Horwath and Paul 1994; Lupwayi et al. 1999). Functional bacterial diversity was evaluated by the Biolog™ method (Zak et al. 1994), which tests the ability of a microbial community to utilize different C substrates contained in a microplate. The procedure was adapted by colorimetrically standardizing inoculum densities in 1 g field-moist soil samples to about 10^3 cells/mL (Lupwayi et al. 2001a). On the basis of the patterns of utilization of the substrates by the bacteria from each soil, Shannon index (H’) of functional diversity was calculated as follows (Magurran 1988; Zak et al. 1994), using PC-ORD software (McCune and Mefford 1997):-

$$H' = -\_p_i (\ln p_i)$$

where p_i = Ratio of activity (i.e., optical density reading) on the *i*th substrate to the sum of activities on all substrates.

At the same time that soil samples were collected for microbiological analysis, shoots of five plants were collected from each plot to measure N uptake after wet digestion with H_2SO_4 + H_2O_2 (Thomas et al. 1967).

At harvest, grain yields were determined from a 1.5 m x 15.2 m area.

Results

Microbial biomass C

In Year 1, cattle manure increased MBC in bulk soil by 26% (to 634 mg/kg soil), but inorganic fertilizers reduced MBC by 20% (to 402 mg/kg soil), compared with the control (503 mg/kg soil) (Table 2). Although hog manure did not increase MBC relative to the control, it increased MBC compared with inorganic fertilizers. Frequency of application (annual or triennial) had no effects on MBC and there were no interactions between nutrient source and frequency of application. In Year 2, no factor affected MBC, but a similar pattern to that observed in Year 1 was evident with respect to nutrient source effects. In Year 3 in bulk soil, cattle manure increased MBC by 86% (to 1383 mg/kg soil), and hog manure increased MBC by 31% compared with the control (742 mg/kg soil). Annual applications increased MBC by 17% relative to triennial application (891 mg/kg soil). In wheat rhizosphere, cattle manure increased MBC by 70% relative to the control (566 mg/kg soil), and frequency of application had no effects. As in Years 1 and 2, there were no interactions between nutrient source and frequency of application in Year 3.

Functional diversity

In Years 1 and 2, H’ was not affected by treatment (Table 2, Year 2 data not shown). In Year 3 in bulk soil, all soil amendments (manures and inorganic fertilizers) increased H’. Frequency of application had no effects on functional bacterial diversity in bulk soil or rhizosphere. There were no interactions between nutrient source and frequency of application.

Crop N uptake

In Year 1, plants that had received hog manure absorbed more N than the control (Table 3). In Year 2, plants that had received inorganic fertilizers absorbed more N than the control. In Year 1, more N was absorbed with triennial application than annual applications, but the reverse was observed in Year 2. In Year 3, there were no effects of nutrient source or application frequency on N uptake. There were no interactions between nutrient source and frequency of application.

Crop yields

Canola grain yields in Year 1 increased by 75% with hog manure (to 1.94 t/ha) and 49% with cattle manure, relative to the control (1.11 t/ha) (Table 3). The effect of application frequency depended on nutrient source: grain yields were reduced when inorganic fertilizers were applied triennially compared with annual applications, but triennial application of organic manures increased yields slightly (interaction data not shown). In Year 2, only cattle manure increased barley grain yields (by 25% to 3.50 t/ha), regardless of frequency of application, compared with the control (2.81 t/ha). In Year 3, cattle manure increased wheat grain yields by 50% (to 3.07 t/ha), inorganic fertilizers by 33% and hog manure by 32%, compared with the control (2.04 t/ha).

Table 2. Microbial biomass C (MBC) and bacterial diversity (H') in bulk soil and rhizosphere (rhizo.). Rhizosphere MBC and diversity were measured in Year 3.

Treatment	MBC (mg/kg soil)				Shannon index (H')		
	Year1	Year 2	Year 3		Year 1	Year 3	
			Bulk soil	Rhizo.		Bulk soil	Rhizo.
Nutrient source (n=8)							
Cattle manure	634*a*	458	1383*a*	960*a*	2.86	2.75*a*	2.62
Hog manure	514*b*	261	969*b*	740*b*	2.67	2.62*a*	2.49
Inorg. fert.	402*c*	219	775*bc*	495*c*	2.85	2.62*a*	2.44
Control	503*b*	285	742*c*	566*bc*	2.98	2.23*b*	2.34
SEM[z] (21 df[y])	30	86NS[x]	68	65	0.10NS	0.09	0.13NS
Application frequency (n=16)							
Annual	498	336	1043*a*	753	2.78	2.57	2.53
Triennial	529	276	891*b*	627	2.89	2.54	2.41
SEM (21 df)	21NS	61NS	48	46NS	0.07NS	0.07NS	0.09NS
Interaction	NS	NS	NS	NS	NS	NS	NS

[z]SEM = standard error of the mean.
[y]df = degrees of freedom for error.
[x]NS = not significantly different at 5% significance level.
a-c Means followed by the same letter in a column (within a treatment category) are not significantly different at 5% significance level according to the Least Significant Difference (LSD) test.

Correlations

H' in bulk soil was negatively correlated with crop N uptake (r = -0.996**) in Year 1, and positively correlated with crop grain yields (r = 0.990**) in Year 3.

Discussion

Cattle manure usually increased MBC more than hog manure. One possible reason is that hog manure contained insufficient C substrate (as reflected in low DM contents relative to cattle manure, Table 1) for microbial cell biosynthesis and energy. The soil had low organic C content (16 g/kg). The increase in MBC and functional diversity with organic manure application is important because soil microorganisms mineralize nutrients from organic soil amendments. Langmeier et al. (2002) reported that a greater proportion of N applied as cattle manure was mineralized in a long-term organically managed soil, characterized by higher soil microbial activity, than in a conventionally managed soil that had received only inorganic fertilizers.

Table 3. Crop N uptake in above-ground plant material, sampled at cereal flagleaf stage or canola flowering stage, and grain yields at maturity.

Treatment	N uptake (mg/plant)			Grain yield (t/ha)		
	Year 1 (Canola)	Year 2 (Barley)	Year 3 (Wheat)	Year 1 (Canola)	Year 2 (Barley)	Year 3 (Wheat)
Nutrient source (n=8)						
Cattle manure	137b	80b	38	1.65*b*	3.50*a*	3.07*a*
Hog manure	238a	91b	43	1.94*a*	2.99*b*	2.69*b*
Inorganic fertilizers	140b	120a	37	1.33*c*	2.98*b*	2.71*b*
Control	88b	68b	35	1.11*c*	2.81*b*	2.04*c*
SEM[z] (21 df[y])	18	8	5NS[x]	0.09	0.14	0.11
Application frequency (n=16)						
Annual	129b	100a	41	1.55	3.12	2.73
Triennial	172a	80b	35	1.47	3.02	2.52
SEM (21 df)	13	6	3NS	0.06NS	0.10NS	0.08NS
Interaction	NS	NS	NS	**	NS	NS

[z]SEM = standard error of the mean.
[y]df = degrees of freedom for error.
[x]NS = not significantly different at 5% significance level.
a-c Means followed by the same letter in a column (within a treatment category) are not significantly different at 5% significance level according to the Least Significant Difference (LSD) test.

Inorganic fertilizers reduced MBC in Year 1, and had no effect on MBC in subsequent years. Similar negative effects of inorganic fertilizers on soil microorganisms have been reported before (Gupta et al. 1988; Lupwayi et al. 2001b; Peacock et al. 2001). Such effects are due to factors like soil acidity and osmotic pressure (Gupta et al. 1988). However, fertilizers can have positive indirect effects by producing healthy crops, whose root exudates would increase microbial growth and activity (Lynch and Whipps 1990). For example, Lupwayi et al. (2001b) observed that sulphur fertilizers decreased soil microbial diversity in bulk soil, but increased diversity in wheat and canola rhizosphere. In addition, fertilizers increase yields of crop grain and residues which, when incorporated into the soil, will stimulate microbial growth (Doran and Linn 1994; Lupwayi et al. 2004).

In Year 1, crop yields were in the order: hog manure > cattle manure > inorganic fertilizers > control, but cattle manure out-yielded other treatments subsequently. The reason is probably because most (72%) of the N in hog manure was in inorganic (ammonium) form, whereas virtually all the N in cattle manure was in organic form (Table 1). Inorganic N is immediately available to crops, but organic N has to be converted to inorganic forms by soil microorganisms before crop roots can absorb it. During this conversion, some of the N gets immobilized into microbial tissue if the manure contains insufficient N (wide C/N ratio) for microbial requirements, but this N is released back into the soil when microorganisms die and decompose. Therefore, hog manure seems to have more immediate nutrient value to crops than cattle manure, as trends in crop N uptake in Year 1 indicated, but cattle manure probably has more residual nutrient value than hog manure.

In Year 2, crop N uptake was greater where inorganic fertilizers had been applied, but crop yields were greater where cattle manure had been applied. In addition, uptake of N was greater with annual applications than triennial application, but crop yields were not affected by application frequency. This means that differences in crop yields were not entirely due to nutrient uptake. In other cases, where H' was positively correlated with crop yields, it was not correlated with nutrient uptake; and where H' was negatively correlated with nutrient uptake, it was not correlated with crop yields. Therefore, other microbiological interactions probably affected crop yields, and biological pest control is a possibility. In field trials and farmers' fields, Conn and Lazarovits (1999) found that as populations of soil bacteria increased by up to 1000-fold with application of N-rich organic amendments, including hog manure, populations of plant pathogens were reduced. Bulluck et al. (2002) found similar results in field trials comparing organic manures with inorganic fertilizers.

Conclusions

Cattle manure usually increased soil MBC, hog manure sometimes increased MBC, and inorganic fertilizers sometimes reduced MBC. All nutrient sources usually increased the functional diversity of soil bacteria. Hog manure increased N uptake and crop grain yields more than other amendments in Year 1, but cattle manure produced the highest grain yields in subsequent years even when N uptake was greatest with inorganic fertilizers. The effects of soil organic or inorganic amendments on soil microbiological properties were usually the same with annual or triennial applications. Whereas N uptake was greater with triennial application than with annual application in Year 1, the reverse was true in Year 2, and there were no differences in Year 3. In Year 1, there were instances of reduced grain yields with triennial applications of inorganic fertilizer or hog manure. Therefore, judicious application of organic manures in the low-C Gray Luvisolic soils should be encouraged to increase crop productivity on a sustained basis due to improved soil biological quality.

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