BIOCHAR: WASTE, OR PRODUCT?

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Abstract

Nutrient losses following summer and fall manure applications result in economic and water quality problems. We tested the potential of biochar (BC) and ammonium thiosulphate (ATS) as manure additives to retain nutrients by reducing nitrate pool size and runoff of N and P. To determine appropriate rates to use in field experiments, the compounds were initially added at different rates to liquid swine manure (LSM) then the slurry mixed with soil and incubated. The selected rates, based on N transformations, were 0.1 kg BC/L LSM and a ratio of 417:1, LSM:ATS. The compounds were added to LSM applied pre-plant for winter wheat at two replicated field experiments. Rates were 39 and 64 m^3 LSM/ha which supplied 4.1 and 5.7 T BC/ha at loam and clay loam sites, respectively. Manure with and without BC was also broadcast on runoff catchments from which nutrient movement overland and to tile drains was monitored. The following preliminary findings indicate that BC addition to manure merits further investigation: a trend of yield response to addition of BC to fall-applied manure at one of two sites; indications that off site movement of N from fall-applied manure is reduced with BC added - lower tile nitrate concentrations (movement to surface water) and lower subsoil solution nitrate concentrations (movement to groundwater); odour was controlled by the addition of BC; and manure viscosity was increased by the addition of BC. Since the effective rate was about 5 T/ha, use of this material will be economical if it is a waste rather than a high value product.

Introduction

Bio-oil production from pyrolysis of waste materials results in an ash-like co-product called biochar (BC), which may enhance carbon storage and reduce N leaching (Lehmann and Joseph 2009), although data from temperate climates are limited. Given its composition, the product when added to manure could control odour, delay N release, improve NPK balance with respect to crop requirements, and render N and P less mobile. There are challenges to overcome in handling this material. Addition of nitrification inhibitors to manure can conserve nitrogen (McCormick et al. 1984; Sawyer et al. 1990; Dittert et al. 2001), but many of these products are not registered in Canada. Ammonium thiosulphate [ATS, $(NH_4)_2S_2O_3$] is a commercially available fertilizer material that can delay nitrification e.g., by 4 to 5 wk in the case of poultry manure-N (Sallade and Sims 1992). Addition of ATS to manure in European field trials has produced mixed results (Goos 2001). If addition of ATS to fall-applied manure slows conversion of manure NH_4-N sufficiently in Ontario, more N will be retained over winter and available to plants the subsequent spring and less transported into surface- and groundwater. This project tested whether addition of BC and ATS to manure conserves nutrients for subsequent crops. Winter wheat, being very responsive to N in early spring, was used as a bioassay for N availability.

Objectives

i) Develop procedures for handling and mixing additives for use in conserving nutrients from manure for enhanced crop uptake and yields;

ii) Evaluate how additions to liquid manures of ATS and BC affect nutrient utilization and offsite transport to runoff, tile and groundwater.

Materials and Methods

Incubation studies

Incubations were conducted to determine appropriate additive: manure ratios for subsequent field trials based on N transformations. Biochar (CQuest BioChar) produced from wood waste by Dynamotive Energy Systems Corporation, or ATS (12-0-0 26S), were added to liquid swine manure (LSM) at different ratios and the slurries analysed within 2 d (Table 1). These slurries (50 mL or equivalent weight) were mixed into 1 kg (air dry basis) of loam soil (3 replicates each). Control treatments were no amendments and manure without any additive. In the first incubation, slurry additions were equivalent to 5, 10 or 20 g BC/kg soil, and 0.12 or 0.24 mL ATS/kg of soil, and soil was pre-wetted to 11% gravimetric moisture content. Following slurry addition, soils were stored at ambient May temperature for 18 d and then at 4^oC for 10 d. Soils were extracted to determine inorganic N after 2 and 4 wk. In a second incubation study: additive rates were 10 or 20 g BC/kg soil and 0.24 or 0.48 mL ATS/kg soil; soil water content was 11% for two replicates, and 19% for a third sample set and the controls; soils were stored at ambient June/July temperature, and were extracted after 1 d, 2 wk and 3 wk.

Field studies

Experiments were conducted on clay loam and loam sites with BC or ATS added to fall-applied LSM, along with appropriate control treatments that tested time of manure application (fall vs spring) and response to spring-applied urea at 146 kg N/ha (130 lb/ac). Treatments were arranged in a randomized block design 4 replications. Biochar was added in proportion to the LSM rate estimated to provide sufficient N for winter wheat, and at a ratio believed sufficient to immobilize N and prevent loss over winter based on the incubation experiments. Fall manure application rates were based on lab analysis at the loam site, and ammonium quick test at the clay loam site (Table 2). LSM NH_4-N content was underestimated by the quick test, so the manure N rate on clay loam was greater than intended (Table 2). The error was caused by an air leak in the AGROS casing which was replaced before the spring testing (Table 2). Prior to fall application, 0.11 kg BC/L was added to LSM at the loam site, which supplied 4150 kg BC/ha; and 0.09 kg BC/L added at the clay loam site, which supplied 5724 kg BC/ha. At both sites, ATS was added at 417:1, manure:ATS v/v (2.4 mL/L), so application supplied 93 L ATS/ha (32 kg S/ha) at the loam and 152 L ATS/ha (52 kg S/ha) at the clay loam site. The LSM + additive slurries were injected in the two replicated experiments since inhibitors work better in a band. To determine the effect of BC addition on nutrient transport overland and to tile, LSM, untreated or with 0.11 kg BC/L, was surface broadcast at 37 m^3/ha on 9 Oct. 2010 on runoff microcatchments constructed in 2007 with and without tile drainage (loam soil). Catchments were under conventional tillage except one no-till microcatchment where LSM (untreated) was injected (Best Management benchmark). Hard red winter wheat was planted on 18 Oct. 2010 at the loam experiment and microcatchments, and on 19 Oct. 2010 at the clay loam experiment. In spring

2011, manure and fertilizer were topdressed at the replicated experiments on 18 Apr. (on frost) at the loam site, and on 9 May 2011 at the clay loam site, delayed by wet weather.

Runoff and tile waters were collected using automated samplers. Nitrate leaching over winter was measured in the runoff catchments and the replicated experiment on loam soil using suction lysimeters. Soil solutions from 0.8 and 1.3 m deep were collected until freeze-up during fall 2010 and after thaw the following spring. Soil inorganic N in KCl extracts from soils of the incubations, in tile water and in soil solutions was determined by flow injection analysis.

Results and Discussion

Incubation studies

Both additives reduced inorganic N concentrations of the soil /manure additive mixture relative to that with manure alone after a few weeks. Soil ammonium-N increased with increasing rates of ATS in both studies for up to 4 wk. Soil nitrate was reduced by all three rates of ATS after 2 wk (both studies), and after 3 wk by both 0.24 mL/kg soil (4.8 mL/L LSM) and 0.48 mL/kg soil (9.6 mL/L LSM) in wet soil (20%), but only by 0.48 mL/kg in dry soil (11%). Slurries of LSM+BC at 10 or 20 g BC/kg soil (0.2 and 0.4 kg/L LSM) reduced soil inorganic N by 10 to 30% relative to untreated manure after 2 or 3 wk in both incubation experiments. In most cases this was due to decreases in both ammonium and nitrate concentrations, indicating conversion to organic- (increased immobilization) or other non-extractable forms

Field studies

Weather during fall 2010 through spring 2011 created a worst case scenario for fall-applied manure. Rainfall was above average in October with 104 mm (66 mm long term average) and in November with 95 mm (vs 66 mm). Heavy rains occurred 2 d after application (24 mm), followed by a number of runoff and leaching events that fall /winter e.g., 20 mm on 21 Oct.; 22 mm on 16-17 Nov.; 26 mm on 22-23 Nov.; 10 mm on 25 Nov.; 25 mm on 30 Nov.; and snowmelt + 43 mm rain 30-31 Dec. 2010 + 23 mm on 1 Jan. 2011 at the loam site. Precipitation was similar at the clay loam site, except more rain fell on both 22-23 Nov. (34 mm) and 25 Nov. (17 mm) than at the loam site. At the clay loam site, some plots suffered ice coverage on several occasions over winter and some were covered by previous crop residues (corn) deposited by concentrated runoff across the experiment. At the loam experiment, water logging was a problem during the very wet spring of 2011, particularly in one block, from which excess surface water was pumped into an excavated pit on several occasions. The data from this block were excluded from the yield averages presented in Fig. 1. With the water-logged block included, yields averaged lower and deviated more from the mean, however treatment rankings did not differ.

There was a trend of greatest yield with BC added to fall-applied manure at the clay loam, but not at the loam site (Fig. 1). The site effect was contrary to expected greater N conservation benefit on lighter soil texture, which would be more prone to leaching losses than heavier soil. On the other hand, since the clay loam site had drainage tile, while the loam site did not, the operative N loss process may have been denitrification rather than leaching at the loam site. The site difference may have been due to the greater application rates of BC and/or manure (ha basis) at clay loam than loam site. Further investigation would be required to confirm the yield trend. Yield response to spring topdress manure was more favourable at the loam than clay loam site

(Fig. 1) which was typical of this treatment comparison in previous years. It may be a response to manure-P at the loam site which has lower soil test P, or to a smothering effect at the clay loam site from top-dressed manure, which usually had higher dry matter content than the manure used at the loam site. There was no yield response to ATS in the replicated experiments (Fig. 1) and no response to surface-applied LSM+BC in the runoff catchments (data not shown).

By-pass flow of manure to tile did not occur at time of application in any of the microcatchments. In systems susceptible to preferential flow of manure to tile, the more than doubled dry matter content of LSM with BC added (Table 2) could be expected to mitigate this risk. Tile water nitrate concentrations were lower with LSM+BC than untreated LSM (Fig. 2). Concentrations during Nov. 2010 through Feb. 2011 averaged 19 mg NO_3–N L^{-1} with LSM+BC and 30 mg NO_3–N L^{-1} from untreated surface-applied LSM. The greater tile water nitrates over winter with injected than surface-applied LSM (Fig. 2) was likely in part due to less volatilization loss with injection. There were no clear trends in nitrate concentrations in runoff or phosphate concentrations in tile or runoff water (data not shown). There was evidence of reduced nitrate leaching through the soil matrix with BC added to manure. In catchments with tile drainage, nitrates moved to 1.3 m deep in the fall and solution concentrations averaged less with LSM+BC than with untreated LSM at both 0.8 and 1.3 m deep (Table 3). In the spring, nitrate concentrations continued to trend lower with LSM+BC than with untreated LSM, in the catchments both with and without artificial drainage, and in the replicated experiment (Table 3). Nitrates had not moved to below 1 m in the fall in the replicated experiment with natural drainage (averaged 4 mg NO_3–N/L).

Practical applications

Risk of spontaneous combustion of BC after long term storage is nil. A manure+BC slurry mixture expands with time e.g., to an additional 10% volume at 0.1 kg BC/L manure. When the addition exceeds 0.4 kg BC/L, liquid manure becomes a solid. At the BC:manure ratio used in the field study, the slurry was notably more viscous and less odorous than untreated manure e.g., much quicker shut off from hoses at the tool bar. The BC is water repellent, but readily mixed by in-tank agitation. When adding BC to manure in a tank applicator, for ease of mixing it is best to partially fill the tank with manure, then add the BC and then the rest of the manure because BC is difficult to mix if added on top. A few hours after being agitated in a manure applicator tank, the BC re-floats back to the surface forming a layer. If this layer remains suspended over the long term, adding BC directly to a manure lagoon may be a practical means for odour reduction and likely preferable given material handling characteristics.

Summary

Preliminary results indicate possible value from addition of biochar to fall-applied liquid manure in terms of crop response and off-site N movement. The dramatic viscosity effect may hold greatest potential to add value to this material, as thick slurry can remedy the problem of by-pass flow to tile drains for susceptible systems. Given the effective rate, use of biochar will be economical as a waste, not a high value product. Improved N utilization could also allow reduced manure application rates without negative yield impact.

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Table 1. Nutrient analysis of biochar (BC), liquid swine manure (LSM), and slurries of BC or ammonium thiosulphate (ATS) plus LSM (after 2 days) used for incubation study

	kg BC or mL ATS /L LSM	C:N	OM	SD[†]	Dry matter	SD	NH_4-N	SD	N	SD	P	SD	K	SD
			%											
BC	-	89.0	79.0	-	99.9	-	0.01	-	0.49	-	0.04	-	0.36	-
LSM	-	3.5	4.5	0.35	5.6	0.42	0.48	0.012	0.69	0.007	0.14	0.014	0.36	0.021
LSM+BC	0.1	9.5	11.7	0.07	14.8	0.07	0.40	0.021	0.67	0.021	0.14	0.000	0.33	0.007
LSM+BC	0.2	13.5	16.4	0.28	20.8	0.35	0.36	0.013	0.67	0.028	0.14	0.007	0.33	0.021
LSM+BC	0.4	22.5	26.2	0.14	33.2	0.21	0.29	0.015	0.64	0.014	0.13	0.014	0.34	0.021
LSM+ATS	2.4	4.5	4.5	0.35	5.7	0.49	0.40	0.163	0.62	0.148	0.12	0.000	0.35	0.007
LSM+ATS	4.8	3.0	4.5	0.49	5.6	0.71	0.57	0.038	0.80	0.057	0.13	0.028	0.37	0.021

[†] standard deviation of 2 replicates

Table 2. Composition of manure or slurry mixture and amount of NH_4-N and total N applied fall 2010 and spring 2011 at two replicated wheat experiments. BC=biochar, ATS= ammonium thiosulphate

Site	Application date	Slurry type	Quick Test NH_4-N	Lab Analysis DM	N	P	K	NH_4-N	Applic. Rate US gal/ac	Amount Applied NH_4-N	Total N
			%						(m3/ha)	kg/ha	
Clay	13 Oct.2010	LSM+BC	-	8.2	0.36	0.09	0.16	0.35	6800 (64)	221	229
Loam	“	LSM+ATS	-	1.2	0.42	0.04	0.16	0.42	6800 (64)	270	270
	“	LSM	0.19	1.0	0.38	0.03	0.18	0.37	6800 (64)	239	248
	9 May 2011	LSM	0.24	1.5	0.27	0.04	0.20	0.26	6200 (58)	149	151
Loam	12 Oct.2010	LSM+BC	-	14	0.52	0.18	0.30	0.45	4150 (39)	175	202
	“	LSM+ATS	-	6.7	0.54	0.18	0.29	0.54	4150 (39)	209	210
	“	LSM	0.20	6.6	0.51	0.19	0.30	0.45	4150 (39)	161	198
	18 Apr.2011	LSM	0.35	8.0	0.56	0.19	0.34	0.41	4300 (40)	166	225

Table 3. Solution nitrate concentrations (average of several lysimeters and 3 dates Oct.-Dec. 2010 or 4 dates Apr.-May 2011) with and without biochar added to liquid swine manure surface-applied in runoff catchments with and without tile, and injected in a replicated experiment, pre-plant for winter wheat

	Depth	Catchments				Replicated experiment
		Tile drainage		Natural drainage		
	m	Fall 2010	Spring 2011	Fall 2010	Spring 2011	Spring 2011
LSM	0.8	35	33	16	21	-
LSM+BC	0.8	25	31	14	10	-
LSM	1.3	31	37	2	16	15
LSM+BC	1.3	25	24	11	12	13

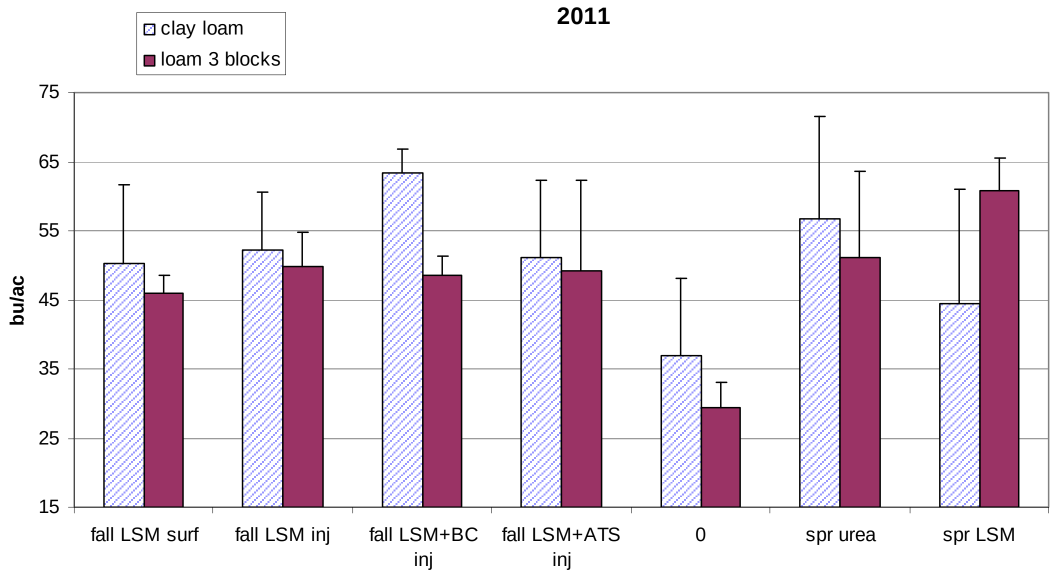

Figure 1. Hard red winter wheat yield (14% moisture) with fall-applied liquid swine manure (LSM) surface-applied (surf) or injected (inj) with or without additives, or spring-applied urea or LSM at clay loam and loam sites. Error bars are standard deviation of 4 and 3 blocks at clay loam and loam sites, respectively

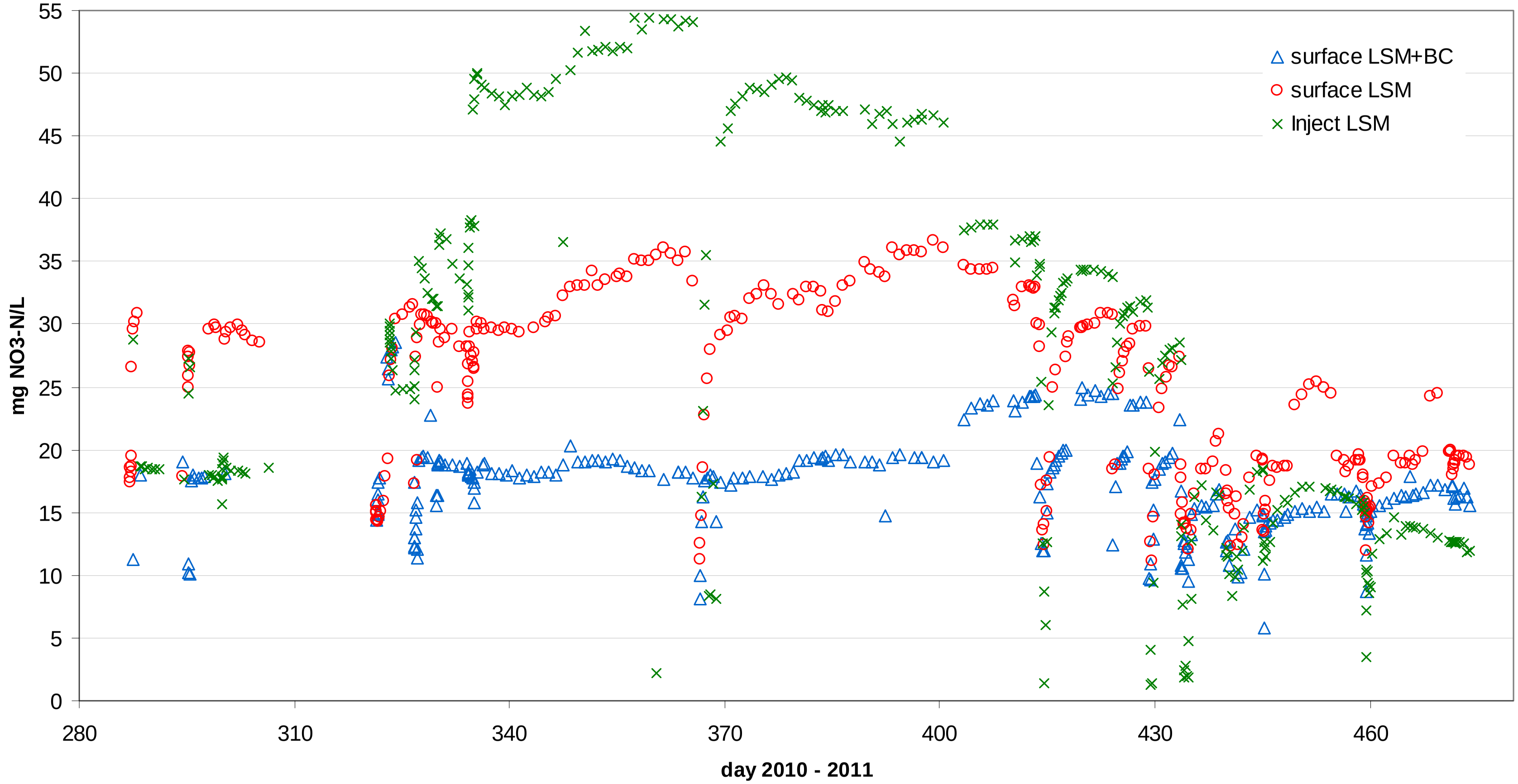

Fig. 2. Nitrate concentration in tile drainage water from start up flow on 14 Oct. 2010 until 19 Apr. 2011 with surface-applied manure (LSM) with or without biochar or with injected LSM, applied 9 Oct. 2010 (day 282) pre-plant for wheat in runoff catchments, loam soil.

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