

Yield, Nitrogen, Phosphorus, Copper and Zinc Uptake by Barley Forage Amended with Anaerobically Digested Cattle Feedlot Manure (ADM)

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Abstract. With increasing production of bio-gas and availability of anaerobically digested cattle feedlot manure (ADM), we need a better understanding of the impact of its application on crop production and the environment. The objective of this study was to investigate nutrient and heavy metal uptake by barley forage from soil amended with ADM. A four-year field study was conducted in southern Alberta to compare annual application of ADM liquid (ADML), and the solid fraction separated from the ADM (ADMS) to raw undigested cattle feedlot manure (CFMR). An unamended control (CK) was also included for comparison. Treatments were replicated four times using a split plot experimental design. All amendments were applied in spring each year prior to seeding and barley was grown and harvested at the soft dough stage for making cattle silage feed. All amendments were applied at rates supplying 100 or 200 kg N ha⁻¹ yr⁻¹, assuming 100% mineral N and 50% organic N was available to crops in the year of application. Averaged over four years, the highest yields were found from ADML (9.55 and 9.6 Mg ha⁻¹ yr⁻¹), and lowest from CK (6.93 Mg ha⁻¹ yr⁻¹), with ADMS and CFMR (7.80 to 8.66 Mg ha⁻¹) in between. Contents and total uptake of nutrients and heavy metals (N, P, Cu and Zn) by barley forage from ADML were higher than ADMS and CFMR. and higher at 200 kg N ha⁻¹ yr⁻¹ than 100 kg N ha⁻¹ yr⁻¹. Our data suggest that anaerobic digestion increases nutrients and heavy metal availability in cattle feedlot manure, but most increases occurred in the liquid fraction. Our data also suggest that the impact of organic amendment application on forage barley production is not only affected by the types of amendment used, but also by agronomic practices (e.g., seeding date) as well as growing conditions.

Key words: Heavy metals, field experiment, barley forage production, anaerobically digested cattle feedlot manure.

Introduction

Bio-gas, mainly methane (CH₄), production through anaerobic digestion of livestock manure has increased steadily over the years (Pitts, 2010) to meet the increasing demand for renewable energy production and environmental sustainability (Gungor and Karthikeyan, 2005; Holm-Nielson et al., 2009). The anaerobically digested livestock manure (ADM) can be applied to land in its liquid form (ADM_L), or separated into liquid and solid fractions (Moller et al., 2006). The liquid fraction can either be used as irrigation water or be recycled back to bio-gas production. The solid fraction (ADM_S) can be applied to soil in a similar manner to raw undigested

livestock manure. The ADM after CH₄ production is rich in nutrients since CH₄ production mainly converts carbohydrate to CH₄ (Holm-Nielson et al., 2009). Additionally, the physical and biochemical properties could be altered during the anaerobic digestion process, affecting the nutrients and metal behavior and availability in soil after their application. We tested this hypothesis under semi-arid field conditions to determine the nitrogen (N) and phosphorus (P) uptake by barley forage in a Dark Brown Chernozemic clay loam soil amended with ADM_L and ADM_S and how they differ from soil amended with raw un-digested cattle feedlot manure (CFM_R),

Materials and Methods

The study was conducted in semi-arid Southern Alberta, Canada on a Dark Brown Chernozemic soil under no-till barley production from 2008 to 2011. Climate data was downloaded from the Agriculture and Agri-Food Canada Weather Station located about 15 km from the study site (Table 1).

Three types of amendments and seven treatments were used in this study. Amendments CFM_R , ADM_L and ADM_S were applied at the recommended rate (ADM_{L1} , ADM_{S1} , and CFM_{R1}) and double the recommended rate (ADM_{L2} , ADM_{S2} and CFM_{R2}) to meet crop N needs. The recommended rate is 100 kg N per hectare per year for silage barley production. We assumed 100% mineral N (KCl -extractable NO_3^- and NH_4^+) and 50% total N in the amendment would be available for crop use in the year of applications. An un-amended control (CK) was also included for comparison. All treatments were replicated four times.

Table 1. Weather conditions during study period

	2008	2009	2010	2011
Growing season [†]				
Evaporation (mm)	1024	1074	667	892
Precipitation (mm)	300	207	163	104
Temperature	16.0	16.6	15.6	17.8
Annual				
Evaporation (mm)	1527	1751	1567	1708
Precipitation (mm)	522	417	607	541
Temperature	6.2	5.8	6.3	6.1

[†]June-Sept. for 2008 and 2009 and July-Sept. for 2010 and 2011; the long-term annual averages for evaporation, precipitation and temperature were 1508 mm, 398 mm and 6.4°C and growing season June-Sept. (July-Sept.) averages were 958 (758) mm, 206 (122) mm and 16.2 (16.4) °C.

Amendments were applied on June 17, 2008, June 4, 2009, June 29, 2010, and July 7, 2011 and barley was seeded the same day or one day after. Barley was harvested as forage for ensiling at the soft dough stage on September 16, 2008, August 29, 2009, Oct 19, 2010, and September 29, 2011. In addition to yield, the forage was analyzed for N, P, Cu and Zn concentration. The total forage N, P, Cu and Zn uptakes were estimated based on yield and their concentration. The N content was determined using a CNS analyzer (Carla Erba, Italy). The P content was determined by digesting samples with 18M H_2SO_4 following the method of Parkinson and Allen (1975), and the P concentration in the digested solution was determined using an EasyChem Pro discrete analyzer. The Cu, and Zn contents were determined by digesting a 0.25 g fine ground sample in a digestion block (Varian, Palo Alto, CA) with 5 mL of 50% HNO_3 and 2 mL of 30% H_2O_2 at 85 °C for 30 min, followed by adding another 2 mL H_2O_2 solution and digesting at 95 °C for an additional 30 min. The Cu and Zn concentrations in the digesting solution were determined

using an atomic absorption spectrometer (Varian Model AA240, Palo Alto, CA).

The data were analyzed using the MIXED procedure (SAS Institute Inc. 2008) with treatment, year and their interactions in the model as fixed effects, and replication and replication \times treatment as random effects. Year was treated as a repeated measures effect to account for potential correlations and different variances among years. Various variance-covariance matrices were fitted and the one with the lowest AICC value was used for the final analysis. The UNIVARIATE procedure was used to check the residuals for normality and for potential outliers before performing the final analysis.

Results and Discussion

Barley forage yield

Barley forage yield was affected by treatment ($P = 0.002$) and year ($P < 0.001$), but not their interaction ($P = 0.154$). Over the four years, barley forage yields from ADM_{L1} ($9.61 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) and ADM_{L2} ($9.55 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) were significantly higher than from CK ($6.93 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) with yields from the other four treatments in between (7.80 to $8.66 \text{ Mg ha}^{-1} \text{ yr}^{-1}$). Averaged across all treatments, 2009 barley yield (11.70 Mg ha^{-1}) was highest, followed by 2008 (9.61 Mg ha^{-1}), then 2010 (8.09 Mg ha^{-1}) and 2011 (4.27 Mg ha^{-1}) was the lowest. Applications of organic amendment provided N, P and other macro- and micro-nutrients, thus barley forage yields were higher than the unamended CK. The yields reflected a greater proportion of N and P nutrients in available form for ADM_L than ADM_S and CFM_R (data not shown). The highest yield in 2009 was aided by good precipitation and an earlier seeding date, which have been shown to produce better yields in this region. The lowest yield in 2011 was due to a late seeding date, and lack of moisture from low precipitation, high temperatures and high evaporation.

Forage N content and total uptake

The forage total N content was affected by treatment ($P = 0.025$), year ($P < 0.001$) and their interaction ($P = 0.002$). For the first two years, N contents were similar among all treatments. The 2010 N content from ADM_{L1} (17.9 g kg^{-1}) and ADM_{L2} (18.3 g kg^{-1}) was higher than CK (12.6 g kg^{-1}) and ADM_{S1} (12.7 g kg^{-1}), with values from other treatments in between (14.0 - 16.6 g kg^{-1}). The 2011 N content from ADM_{L2} (17.5 g kg^{-1}) was similar to ADM_{L1} (15.2 g kg^{-1}), and ADM_{S1} (12.7 g kg^{-1}), but higher than CK (10.5 g kg^{-1}), CFM_{R2} (11.8 g kg^{-1}), ADM_{S1} (10.7 g kg^{-1}) and ADM_{S2} (10.5 g kg^{-1}). The N content decreased over the years for CK, CFM_{R1} , CFM_{R2} , ADM_{S1} and ADM_{S2} treatments but not for ADM_{L1} and ADM_{L2} . The lower N contents from CK and ADM_{S1} in year 3 and from CK, CFM_{R2} , ADM_{S1} and ADM_{S2} in year 4 suggest soil N supply in those treatments might not be sufficient to meet barley forage production needs. This was consistent with decreases in forage N content over time for those treatments and lower soil available N

content at the end than prior to the onset of the experiment (data not shown). For a semi-arid region, the mineralization of organic N is limited by the lack of moisture and was probably much lower than the 50% rate we assumed in our study.

Total N uptake was affected by treatment ($P < 0.001$) and year ($P < 0.001$), but not their interaction ($P = 0.287$). Total N uptake was highest from the two ADM_L treatments (155 and 167 kg N ha⁻¹ yr⁻¹), and lowest from CK (102 kg N ha⁻¹ yr⁻¹), with values (111-128 kg N ha⁻¹ yr⁻¹) from other treatments in between. The total N uptake from year one (159 kg N ha⁻¹ yr⁻¹) was similar to year two (176 kg N ha⁻¹ yr⁻¹). Both were higher than year three (125 kg N ha⁻¹ yr⁻¹) with values from year four (55 kg N ha⁻¹ yr⁻¹) the lowest. The differences in total N uptake largely reflect the large yield differences, but forage N contents also contributed to the reduced N uptake since N uptake reductions were greater than the yield reductions over the years.

Forage P content and total uptake

The P content was affected by treatment ($P < 0.001$), year ($P < 0.001$) and their interaction ($P < 0.001$). The P content was generally higher in CFM and lower in ADM_L and CK treatments for the first two years, with no differences among treatments in year four. The forage barley P content decreased over the four years for all treatments, except the two ADM_L treatments, whose P contents in year three were higher than other years. Similar to N, our forage P data suggests that amendment application rates used in this study were lower than barley forage requirement.

Similar to N, the total P uptake was affected by treatment ($P = 0.002$), and year ($P < 0.001$), but not their interaction ($P = 0.152$). Total P uptake was highest from the CFM_{R2} treatment (16.3 kg P ha⁻¹ yr⁻¹), and lowest from CK (11.7 kg P ha⁻¹ yr⁻¹), with values (13.9-14.6 kg P ha⁻¹ yr⁻¹) from other treatments in between. The total P uptake was in the order of year two (20.4 kg P ha⁻¹ yr⁻¹) > year one (16.5 kg P ha⁻¹ yr⁻¹) > year 3 (14.2 kg P ha⁻¹ yr⁻¹) > year four (5.6 kg P ha⁻¹ yr⁻¹). The differences among treatments were much smaller in total P uptake than in N uptake. The low N and P uptake in year four was mainly due to extremely low forage yield from a late seeding date and unfavorable weather conditions right after seeding. Similar to N, lower P uptake in year four largely reflect the reduced yield, but lower forage P contents also contributed to the reduced P uptake since the uptake reductions were greater than the yield reductions.

Forage Cu content and total uptake

The Cu content was affected by treatment ($P = 0.042$), year ($P < 0.001$) and their interaction ($P = 0.012$). The Cu content from the two ADM_L treatments was higher than other treatments in years one and two while values were similar among all treatments in years three and four. For most treatments, Cu contents from years one and two were higher than values from years three and four. The

Cu levels for year one and two feed (9.2 -16.7 mg kg⁻¹) were at or above the minimum level (10 mg kg⁻¹) for growing cattle while low levels observed in years three and four (3.8-8.2 mg kg⁻¹) suggest Cu supplementation would be needed when feeding this forage to cattle.

The total Cu uptake was affected by treatment ($P < 0.001$), year ($P < 0.001$) and their interaction ($P < 0.001$). Similar to the Cu content, Cu uptake was higher from the two ADM_L than other treatments for the first three years with no differences among treatments in year four. For most treatments, Cu uptake was also high in years one (77-143 g ha⁻¹) and two (94-248 g ha⁻¹), decreased in year three (28-62 g ha⁻¹) and was lowest in year four (28-37). The reduction in Cu uptake in year four was greater than the reduction in yield. This suggests late seeding not only affected yield, but also decreased Cu uptake.

Forage Zn content and total uptake

The Zn content was affected by treatment ($P = 0.023$) and treatment × year interaction ($P = 0.026$), but not the year ($P = 0.156$). The Zn content for ADM_{L2} in year two was higher and ADM_{S2} in year four lower than other treatments. But Zn contents (14.3-25.5 mg kg⁻¹) observed in our study were all below the minimum levels (30 mg kg⁻¹) to meet cattle needs and lower than values reported for typical barley silage feed (28 mg kg⁻¹).

Total Zn uptake was affected by treatment ($P < 0.001$), year ($P < 0.001$) and their interaction ($P < 0.038$). Similar to Cu, the Zn uptake was higher from the two ADM_L than other treatments. For most treatments, the Zn uptake was also high in years one (135-202 g ha⁻¹) and two (151-327 g ha⁻¹), decreased in year three (112-182 g ha⁻¹) and was lowest in year four (62-88 g ha⁻¹). The reduction in Zn uptake in year four was similar to reduction in yield. This suggests late seeding did not affect the rate of Zn uptake. The reduction in total uptake mainly reflected reduced yield.

In summary, yield, content and total uptakes of nutrient's and heavy metals (N, P, Cu and Zn) by barley forage from ADM_L were higher than ADM_S and CFM_R. Our data suggest that anaerobic digestion increases nutrients and heavy metal availability in cattle feedlot manure, but most increases occurred in the liquid fraction. Our data also suggest that the impact of organic amendment application on forage barley production is not only affected by the types of amendment used, but also by agronomic practices (e.g., seeding date) as well as growing conditions.

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