NITROGEN DYNAMICS OF BIODYNAMIC HORN MANURE

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ABSTRACT

BIODYNAMIC AGRICULTURE ORIGINATED in the 1920s and was a progenitor of modern organic farming. A unique element of biodynamics is the horn manure preparation, which is made by filling cow horns with cow manure in the fall, burying them in topsoil over the winter, and applying the contents to soil as a dilute, aerated spray. To further our understanding of the preparation, a research project was conducted in which horn manure was characterized using standard techniques for compost analysis, and employing glass jars as a control treatment. Across multiple experiments we observed significantly higher total nitrogen, higher nitrate, lower pH, and lower respiration in manure buried in horns compared to jars. Furthermore, there was an inverse relationship between nitrate and pH, possibly due to the stoichiometry of nitrification. In one experiment, a mass balance calculation indicated no significant loss of nitrogen in the horns compared with 37% loss in the jars. We conclude that using horns as vessels promotes different nitrogen dynamics in manure compared to glass jars.

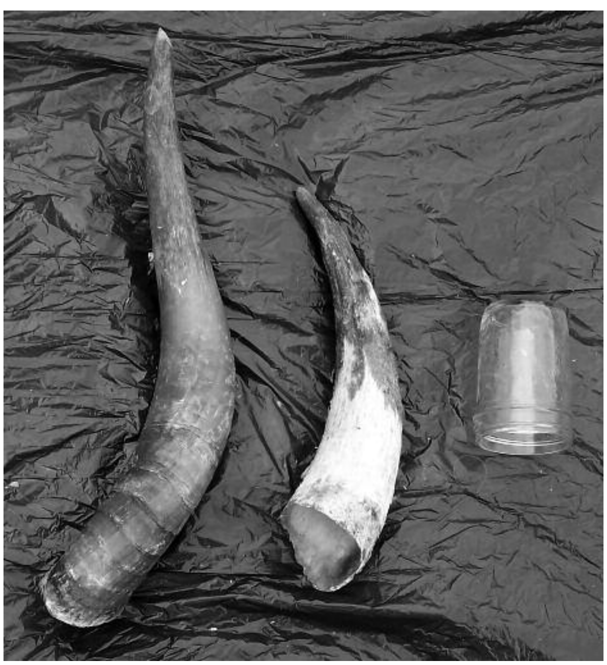

Figure I. Cow horn C1, bull horn B1, and glass jar J1 (left to right) at the NY site in Experiment I, with volumes of 300, 260, and 240 mL, respectively. Color versions of all figures are available online at www.biodynamics.com/nitrogen-dynamics.

INTRODUCTION

Biodynamic agriculture originated in Europe in the 1920s as an alternative to the trend toward greater use of inorganic fertilizers. As with other pioneering movements in organic agriculture, biodynamics emphasized the recycling of plant and animal materials to promote fertility. Biodynamic certification also requires the use of various preparations, which are applied in dilute amounts and believed to enhance soil fertility, prevent disease, or promote the ripening of crops. The focus of the present study is horn manure (also known as "500"), which is made by filling cow horns with cow manure in the fall and burying them in topsoil over the winter. After mixing with water and vigorously stirring for one hour, the horn manure is applied as a dilute soil spray at concentrations ranging from 100 to 300 g ha^{-1} (Koepf et al., 1976; Sattler and von Wistinghausen, 1992). No scientific consensus exists as to the effect of the horn manure preparation, but it was originally proposed to supplement and enhance the fertilizing effect of spreading manure (Steiner, 1924).

The series of experiments reported here were initiated as an attempt to replicate the results of Brinton (1986), who conducted a study in which cow horns, bull horns, and glass jars were filled with the same manure and buried together in one pit. According to Brinton (1986), only the cow horns produced well-ripened material with a characteristic suite of chemical changes. The bull horns and glass jars promoted little change in either the chemical or sensory characteristics compared to the initial manure. When the first experiment of the present study did not fully confirm these results, two different follow-up experiments were conducted the following year. The principal objective has been to characterize the sensory and chemical properties of horn manure, as well as to investigate the influence of the type of vessel, the site, and the manure source.

MATERIALS AND METHODS

See the supplementary information online at www.biodynamics.com/nitrogen-dynamics.

RESULTS

Experiment I

A comparison of cow horns, bull horns, and glass jars (Fig. 1 and 2) as vessels for overwintering manure was conducted at four sites with a history of biodynamic management (Kinderhook, NY; Noti, OR; Woolwine, VA; Calistoga, CA). At every site the cow horns produced material with sensory qualities resembling compost rather than raw manure, i.e., dark brown color, woodsy odor, and colloidal texture. Several bull horns at each site produced material with comparable appearance to the cow horn specimens, but over five replicates the bull horns appeared to promote sensory transformation less completely or less consistently than the cow horns. For example, in OR one bull horn specimen (B3) was very manure-like in its smell and appearance.

At all three sites where the glass vessels were half-pint canning jars (NY, OR, VA), modest to substantial sensory transformation was observed, but the jar specimens were also distinguishable from the horn specimens. The odor was commonly described as neutral—not unpleasant, but not "woodsy" like the horn manure. The glass jar specimens were also notably more fibrous than the horn specimens. The glass jars used in CA, which were larger and had a narrow opening (Fig. 2B), produced material with a strong ammoniacal smell and greenish color like raw manure.

Laboratory results for the initial manures and the unearthed specimens are reported in Supplementary Table S1 online (http://www.biodynamics.com/nitrogen-dynamics). Analysis of variance was conducted for the three sites where the horns and jars were well-matched for volume (OR, NY, VA). The results, shown in Table 1, indicate that there was no effect of the vessel on organic C content. For total N, the cow and bull horns both had a mean of 2.2% N, which was significantly higher than the jar value of 1.8% N ($p = 0.01$). For the CA site, the difference in total N between the horn and jar specimens was even larger (2.0% N horn > 1.2% N jar, $p = 0.005$).

Visual inspection of the results for pH and nitrate-N (Table S1) revealed a strong interaction with location. In OR and CA, the bull and cow horn specimens tended to acidify and accumulate nitrate, and the inverse relationship between these two properties is illustrated in Fig. 3 using values standardized within each location. Unlike the horns, the contents of the jars did not acidify or accumulate nitrate. Furthermore, the OR bull horn specimen (B3) with an appearance similar to raw manure is the outlier that groups with the jars in the upper left of Fig. 3. Some of the NY horn specimens accumulated nitrate but did not acidify, while neither phenomenon was observed in VA (Table S1).

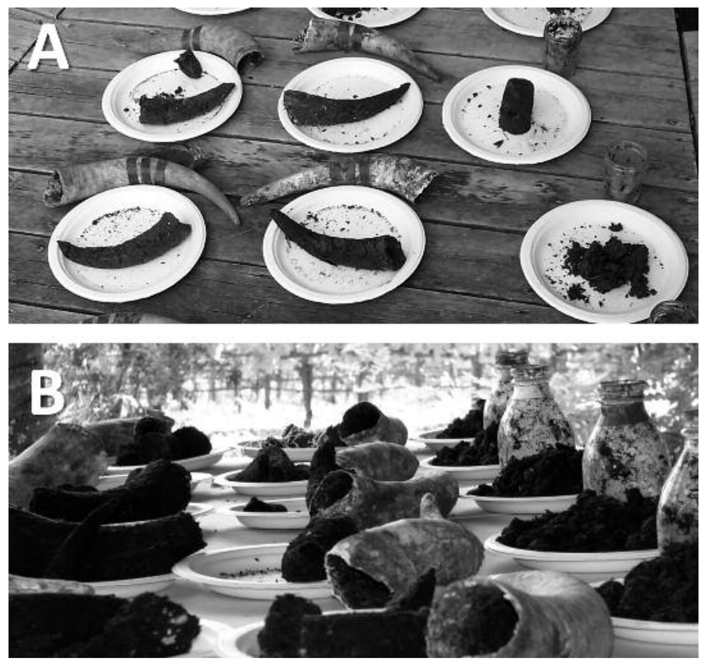

Figure 2. Unearthed specimens in Experiment I. (A) At the OR site. From left to right are the cow horns, bull horns, and glass jars. (B) At the CA site. From left to right are the bull horns, cow horns, and glass jars, which were different than the half-pint jars used in VA, NY, and OR.

Table I. Analysis of variance for the OR, NY, and VA sites in Experiment I.

	F-test p-value			Vessel Mean[†]		
Trait	Vessel	Location	Vessel*Loc	Cow Horn	Bull Horn	Glass Jar
Dry matter (%)	0.13	0.0003	0.2	22	23	25
Organic C (%)	0.4	$< 10^{-4}$	0.4	36	34	34
Total N (%)	0.01	$< 10^{-4}$	0.5	2.2[a]	2.2[a]	1.8[b]
C/N ratio	0.004	0.0009	0.3	16[a]	16[a]	20[b]

[†] Means with different letters were significantly different at the 0.05 level.

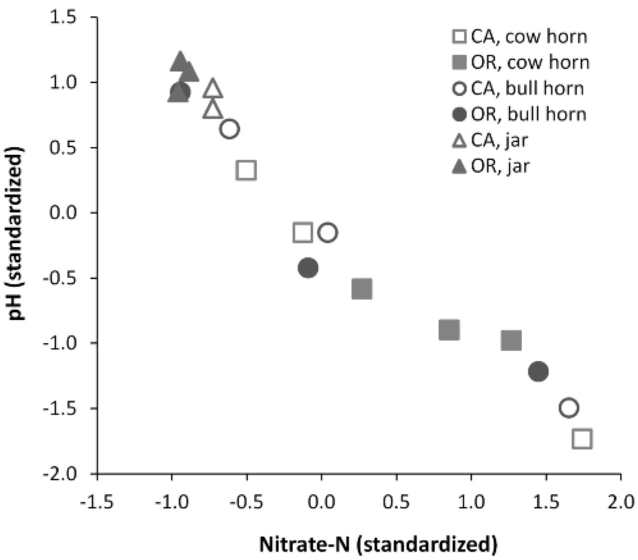

Figure 3. Inverse relationship between pH and nitrate-N at the CA and OR sites in Experiment I. Values have been standardized within each location by subtracting the mean and dividing by the standard deviation. A clear distinction between the contents of the jars vs. horns was observed.

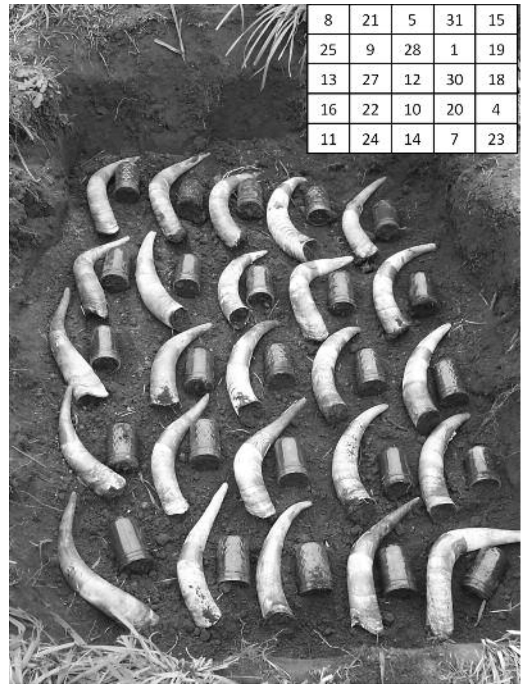

Figure 4. Experiment 2 at burial, with five manures buried in five cow horns and five glass jars (one manure was not analyzed in the spring). The whole plot numbers in the upper right corner correspond to the plot numbers in Supplementary Table S2.

Experiment 2

A limitation of Experiment 1 was that manure source was confounded with location, making it impossible to distinguish the influence of these two factors. Experiments 2 and 3 were conducted the following year to resolve this question. In Experiment 2, four different manures (coded A,B, D, E) from local farms were buried together at the OR site, both in horns and half-pint canning jars (Fig. 4). The unearthed horn manure specimens were generally more compost-like than the jar specimens with respect to color, texture, and odor. However, the horn specimens were also quite variable and were ranked B > E > A > D in terms of sensory quality. Complete results for the laboratory analysis of the initial and unearthed specimens are reported in Supplementary Table S2 online.

Analysis of variance was used to test for differences between the horns and jars, and the results are shown in Table 2. As in Experiment 1, the horns had a higher concentration of total N than the jars (2.6 > 2.1%, $p = 0.002$), but there was no significant difference in organic C concentration. The horn specimens also had a lower respiration rate than the jars (101 < 174 mg CO_2-C kg^{-1} h^{-1}, $p = 0.02$). As in Experiment 1, only the horns accumulated nitrate and acid, not the jars, but the four manures appeared to have different potentials for nitrate accumulation. As shown in Fig. 5, all four replicates of manure B had high levels of nitrate and low pH, whereas only two of the four horns showed this phenomenon for the other three manures. The results in Table S2 show that the horns with lower nitrate levels also tended to have poorer sensory rankings. Neither the horn volume, the horn weight/volume ratio, or the position of the horns in the pit appeared to explain which two of the four horns accumulated nitrate and acid for manures A, D, and E. Furthermore, the lab analysis of the initial manure samples (Table S2) provides no indication as to why manure B showed the greatest propensity for nitrate accumulation.

Mass balance calculations were used to estimate the loss of dry matter, organic C, and total N during the course of the experiment. When the vessels were unearthed, it was visually apparent that the jars had lost substantial material, and this was confirmed by the analysis: on average the jars lost 32% of the initial dry matter while the horns lost only 8% ($p < 10^{-4}$). Although the concentration of organic C on a dry matter basis was not significantly different between the two vessels, the horns lost only 27% of the initial organic C compared with a 49% loss for the jars ($p < 10^{-4}$). The difference between the vessels was even more pronounced for total N: whereas the loss of total N was not significantly different than zero for the horns (95% confidence interval = (-17) – 9%), the jars lost 37% of their initial total N (95% CI = 29 – 45%).

Table 2. Analysis of variance for Experiment 2.

	F-test p-value			Mean[†] [95% Conf. Interval]	
Trait	Vessel	Manure	Vessel*Manure	Horn	Jar
Dry matter (%)	0.3	0.8	0.6	19	18
Organic C (%)	0.7	0.2	0.6	36	35
Total N (%)	0.002	0.002	0.5	2.6[a]	2.1[b]
C/N	0.02	0.01	0.2	14[a]	16[b]
Nitrate-N (mg kg^{-1})	0.0003	0.01	0.02	2080[a‡]	43[b‡]
pH	0.0008	0.3	0.3	6.6[a]	7.8[b]
Respiration (mg CO_2-C kg^{-1} h^{-1})	0.02	0.8	0.7	101[a]	174[b]
Dry matter loss (%)	$< 10^{-4}$	0.6	0.3	7.8[a] [-2.5,18]	32[b] [21,42]
Organic C loss (%)	$< 10^{-4}$	0.2	0.4	27[a] [22,32]	49[b] [44,54]
Total N loss (%)	$< 10^{-4}$	0.06	0.2	-4[a] [-17,9]	37[b] [29,45]

[†] Means with different letters were significantly different at the 0.05 level.
[‡] Interaction with manure was also significant: see Fig. 5.

Experiment 3

The objective of Experiment 3 (carried out concurrently with Experiment 2) was to determine whether manure from the VA source, which did not accumulate nitrate or acid when buried in VA in Experiment 1, would behave similarly when buried in CA. Manure from the VA farm was shipped to CA and buried alongside the CA manure, in both cow horns and half-pint canning jars. When unearthed in the spring, the VA and CA horn manures were both judged to have sensory properties similar to compost. Despite its well-ripened appearance, the VA manure did not accumulate nitrate or acid in the horns; only the CA manure showed this phenomenon (Supplementary Table S3 online). As in the other experiments, only the horns accumulated nitrate and acid, not the jars. Excluding specimen CA-H1, which was a clear outlier, the horn specimens for both manure types had significantly lower respiration than the jar specimens (66 < 126 mg CO_2-C kg^{-1} h^{-1}, $p = 0.001$).

DISCUSSION

The present study was initiated as a replication of an experiment reported by Brinton (1986), in which cow horns, bull horns, and glass jars were compared as vessels for overwintering manure. A number of the key findings from Brinton (1986) were confirmed, including that, compared to glass jars, cow horns tend to produce material with higher total N, higher nitrate-N, lower pH, and lower respiration. Brinton (1986) also reported higher organic matter in his cow horn manure, but we did not observe differences in organic C (as % dry matter). As in Brinton (1986), our cow horn manures were more similar to compost than the jar specimens in terms of texture, smell, and color.

Whereas Brinton (1986) observed the bull horn and glass jar specimens to be most similar (and different from the cow horn specimens), the bull horns in our Experiment 1 produced material that was most similar to the cow horn specimens. One possible explanation for this discrepancy is the difference in horn morphology between the studies. The ratio of the horn weight to cavity volume for the cow horns in Brinton (1986) was on average 3.4 g/mL compared to 1.4 for his bull horns, whereas our cow horns had ratios between 1 and 2 and the bull horns were around 0.5. Brinton (1986) did not report the volumes of his cow horns, but from the published photograph they look smaller than the bull horns, which suggests the volumes of his bull horns may have been substantially larger because cow horns have thicker walls and tips. In our experiment we tried to select horns with comparable volume, reasoning that transformation may be more difficult in a bigger cavity with a smaller surface to volume ratio.

Additional studies described in Brinton (1986) demonstrate the potential for variation in the properties of horn manure across sites and manures. We also observed significant variation in the chemical properties of the cow horn specimens across locations in Experiment 1, and the results from Experiments 2 and 3 implicate the manure source as an important factor in this variation. In particular, we observed that manures have different potentials for nitrate accumulation and acidification. Even among horns with the same manure there can be substantial variation,

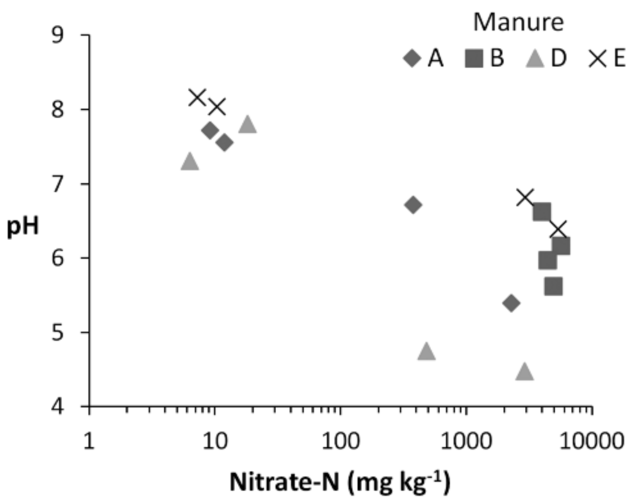

Figure 5. Inverse relationship between pH and nitrate-N for the horn manures in Experiment 2. Four manures (A, B, D, E) were analyzed in one pit, and each data point corresponds to one horn specimen. All four replicates of manure B accumulated nitrate, while the other three manures were more variable.

as documented by the inverse relationship between nitrate and pH. Such a relationship may be explained by the stoichiometry of nitrification, which produces two acid equivalents for every ammonium molecule converted to nitrate (Brady and Weil 2002): $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$. Nitrate accumulation has also been associated with a decrease in pH in studies of aerobic pile composting (Eklind and Kirchmann, 2000).

One of the conclusions in Brinton (1986) was that the transformation of the manure in the cow horns seemed exceptional compared to typical aerobic composting. In particular, he argued that the extent of oxidation observed in the cow horn manure (as reflected in the sensory characteristics, nitrate levels, and oxidation-reduction potential) would ordinarily be associated with larger losses of organic matter and total nitrogen than was observed. Using the ash content as an internal standard, Brinton (1986) reported N losses of 10–20% for several (but not all) of his experiments. Ash content was not measured in this study, but in Experiment 2 we measured the initial and final weights of the horns carefully enough to estimate N loss on an absolute basis, and the mean across the four manures was not significantly different than zero. By contrast, the jar specimens lost 37% of their initial N while showing fewer signs of humification compared to the cow horn manures.

While the levels of N retention for the horn manures in this study and in Brinton (1986) are high compared to many reports of aerobic composting, they are not unprecedented. Eghball et al. (1997) reported N losses as low as 19% of the initial total N after 110 days of composting beef cattle feedlot manure. In the experiment of Inbar et al. (1993), only 15% of the initial N (per unit ash) was lost after 147 days of aerobically composting solid cattle manure. In aerobic pile composting, most of the N losses occur via ammonia volatilization, which is promoted by high temperatures and high pH, while nitrate accumulation occurs at lower temperatures during the curing phase (USDA 2000). Petersen et al. (1998) described a cattle manure compost that did not rise above 30°C and for which only 5% of the initial N was volatilized as ammonia. Although temperatures were not monitored in our study, the small quantities of manure inside each horn and their burial over the winter both suggest that significant heating does not occur. Combined with the low N loss and low pH of the horn manures in the spring, these results indicate the horn manure transformation may occur primarily through a low-temperature curing process.

Spaccini et al. (2012) have also suggested that horn manure may have distinct properties from aerobic compost. In that study, three commercially available horn manure products in Italy were characterized using both NMR spectroscopy and gas chromatograph-mass spectrometry. The authors identified a number of features that, based on their experience, seemed atypical for aerobic compost. This conclusion is interesting but should be viewed as tentative because manure is highly variable and no aerobically composted control was used. To address the question of how the horn manure process is different than aerobic composting, future research should apply both treatments to the same manure source (and use multiple sources).

CONCLUSION

Building on the earlier work of Brinton (1986), the present study has shown that a characteristic set of chemical and sensory changes occurs when cow manure is buried over the winter in horns, and these changes do not occur in glass jars. The horn manure transformation involves nitrate and acid accumulation, minimal nitrogen losses, and the emergence of sensory properties reminiscent of aerobic compost. Despite its resemblance to aerobic compost, horn manure is produced by a very different process. Future research comparing the effect of aerobic composting versus overwintering in horns, using the same manure source, may yield insights on how to assess horn manure quality.

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