TEXAS CATTLE FEEDERS ASSOCIATION

5501 I-40 W.
Amarillo, TX 79106-4617
(806) 358-3681
FAX (806) 352-6026
info@tcfa.org
www.tcfa.org

Monte Cluck
Chairman

Mike Engler
Chairman-Elect

Bo Kizziar
Vice Chairman

Ross Wilson
President & CEO

June 8, 2009

Ms. Lisa Jackson, Administrator
Environmental Protection Agency
EPA Docket Center (EPA/DC)
Mailcode 6102T
1200 Pennsylvania Avenue, NW.,
Washington, DC 20460

RE: Comments on Proposed Rule for Mandatory Reporting of Greenhouse Gases, Docket ID No. EPA–HQ–OAR–2008–0508

Dear Ms. Jackson:

Thank you for the opportunity to submit comments on the proposed rule for mandatory reporting of greenhouse gases (GHGs).

Texas Cattle Feeders Association (TCFA) represents cattle feeders in Texas, New Mexico and Oklahoma—an area that markets almost 30% of the nation's fed beef every year.

On April 10, 2009, the EPA proposed a rule requiring the mandatory reporting of greenhouse gases. TCFA is opposed to this rule. The "2009 U.S. Greenhouse Gas Inventory Report" indicates that **all** agricultural GHG emissions are less than 6% (5.77%) of the total U.S. greenhouse gas emissions for year 2007. Emissions from beef cattle manure management is a fraction of that amount and should not be regulated. Because the livestock industry is such a small source, our members should be allowed to voluntarily reduce greenhouse gases by creating offsets for use by regulated industry as a way to reduce economic burdens imposed by a mandatory cap and trade program.

As proposed, Section IV.JJ—Manure Management would require beef cattle producers to report CH_4 and N_2O emissions from manure management activities. This would primarily include GHG emissions from drylot corrals and stormwater ponds. However, we encourage EPA to closely evaluate the relative contribution of these activities to the total U.S. GHG emissions. The relative contribution of GHG emissions from beef cattle manure management activities has actually decreased from 1990 to 2007. Total CH_4 and N_2O emissions from beef cattle manure management were 8.1 Tg CO_2e in 1990 and 9.1 Tg CO_2e in 2007. These totals represent only 0.133% of total GHG emissions in 1990, declining to 0.127% in 2007. Clearly, the additional burden placed on all beef cattle producers (as proposed in the rule – see below for details) will not provide data that is useful in addressing EPA's long-term goal of reducing major sources of GHG emissions. The incremental increase of GHG from non-agricultural segments is much greater than the minor incremental increase from beef cattle production in the U.S. observed from 1990 to 2007.

Specific Comments on the Preamble Language of the Proposed Rule

Preamble, Section I. Background (p. 16452)

In this section EPA states, "The proposed rule would apply to certain downstream facilities that emit GHGs (primarily large facilities emitting 25,000 tons per year of CO_2 equivalent GHG emissions or more)…" TCFA contends that EPA's determination that the mandatory reporting threshold should be set at 25,000 MT CO_2e per year was based on an inadequate analysis of the sector-by-sector emissions estimates. This faulty analysis masks the significant number of facilities in the beef industry that would be required to report under the rule. A more accurate analysis and data are provided in other comment sections below. If faulty analysis similarly applies to sectors outside of the beef industry, the 25,000 tons/year threshold would bring in many more smaller sources that, based on expressed concerns in the Preamble about limiting the number of entities required to report, EPA apparently does not intend to bring in. It seems unreasonable and counterproductive to require a significant number of smaller facilities to report their emissions. The cost and effort of doing so from both the facility's and EPA's perspectives generates very little meaningful data, relative to the GHG contribution from beef cattle facilities. A reasonable starting point might be for EPA to require reporting from entities that are currently regulated under the Title V program since these sources may be the largest greenhouse gas emitters in the economy. In addition, reporting from Title V facilities would bring in a more sophisticated and a smaller population of reporters. They are already accustomed to frequently reporting complicated information and often have internal environmental staff to ensure compliance with the regulation. Most cattle facilities do not have such internal staff. Consequently, they would have to hire outside consultants at significant cost. At a time when much of the US economy is finding it hard to stay in business, this kind of added expense may very well send many over the edge. In sum, TCFA urges EPA to correct errors in the threshold estimates and evaluate additional reporting thresholds that would more appropriately represent the "large facilities" (i.e., 50,000 MT/year and 75,000 MT/year).

Preamble, Section I.E. How does this proposal relate to U.S. government and other climate change efforts? (p. 16455)

EPA suggests that, "In addition, the data collected on some source categories such as landfills and manure management, which can be covered by the CAA, could also potentially help inform offset program design by providing fundamental data on current baseline emissions for these categories." We disagree with this statement. A **mandatory** reporting requirement is not a required prerequisite for the development of a **voluntary** offset program. Already today, there are several options for agricultural producers to determine carbon offset management practices that can be marketed in established trading programs. TCFA members are interested in potential opportunities that may exist to create voluntary offsets as a way to decrease costs of a cap and trade program anticipated to be passed by Congress. These kinds of voluntary opportunities should be allowed and encouraged rather than using the strong arm of the federal government to regulate minor emission sources, like agriculture, under a mandatory program.

Preamble, Section III.E. What records must I retain? (p. 16463)

> The proposed rule would require "annual" reports and development of a Quality Assurance Project Plan (QAPP). We recommend that EPA remove the requirement for annual reporting for those facilities where estimates of GHGs will not significantly change from one year to the next. EPA could establish a provision whereby a facility that is initially subject to this rule is only required to submit follow-up reports in cases where there have been a significant increase in GHG emissions (i.e., greater than a 25% increase in annual emissions). Additionally, the proposed rule does not include required elements of a QAPP. This requirement can have a major time and expense impact on businesses. Some estimate that a QAPP would result in significant costs. EPA has greatly underestimated the costs of complying with this reporting rule for manure management facilities if a QAPP is required. TCFA strongly urges the EPA to rethink the need for this requirement.

Preamble, Section IV.B. Rationale for Selection of Source Categories To Report— Emissions from agricultural sources and other land uses (p. 16466)

> TCFA strongly supports EPA's decision not to require reporting of GHG emissions from enteric fermentation. We agree with statements in the proposed rule clarifying that enteric fermentation is NOT considered an anthropogenic emission source. Enteric fermentation produces methane as a by-product of a natural digestive process in herbivores in which microorganisms break down carbohydrates for absorption into the bloodstream of the animal. EPA acknowledges in the "Technical Support Document for Biologic Process Sources Excluded from this Rule," February 4, 2009 that there are only two approaches for monitoring methane emissions from enteric fermentation: direct measurement and modeling. "Since direct measurement is prohibitively expensive and overly burdensome for reporters, modeling enteric emissions with emission factors is the only reasonable alternative." *Id.* at p. 6. But EPA states that modeling can result in a high degree of uncertainty due to overestimating variables by 50% or underestimating by 33%. *Id.* Such uncertainty would produce results in which the EPA and industry could not be confident, and would therefore not be appropriate.
>
> TCFA also supports EPA's decision not to include emissions from field burning of agricultural residues, stand-alone composting facilities, agricultural soil management and other land uses and land-use changes since emission estimation techniques for these sources would produce large amounts of uncertainty and would require an extensive effort on the part of reporters. *Id.* at 13, 16, 20, 24, 34. Finally, TCFA is curious about the point at which EPA decides whether a process is anthropogenic or nonanthropogenic. All emissions from manure in open air cattle feeding facilities are the result of biological processes. Manure is excreted by cattle, hits the ground, and stays there until scraped up and removed by facility personnel. During the time it is on the ground where it naturally would be found in its natural state, manure emits methane when natural conditions are anaerobic or nitrous oxide when natural conditions are aerobic. There is nothing manmade about these biological processes. Is it at the point when manure is scraped off the feedyard floor that emissions from manure transform from being natural to anthropogenic, or is it at a different stage? Is it simply the fact that cattle are in closer confines in a feedyard? Why does this fact make a difference regarding natural or anthropogenic sources? TCFA submits that biological processes associated with manure at open air cattle feedyards are natural and not anthropogenic. Consequently, we do not believe it is appropriate for EPA to include manure management from open air cattle facilities in the list of source categories that are required to report under this proposed rule, especially in light of the fact that these emissions (all combined) represent less than 0.127% of total U.S. GHG emissions.

Preamble, Section IV.B. Rationale for Selection of Source Categories To Report— Emissions from agricultural sources and other land uses (p. 16467)

We concur with EPA's justification to exclude N_2O emissions from fertilizer application and fields. As stated in the proposal, "there are no direct greenhouse gas emission measurement methods available except for research methods that are prohibitively expensive and require sophisticated equipment." The ability to obtain economically feasible facility-by-facility estimates of N_2O emissions from fields does not exist today. In addition, it should be noted that food production is an essential part of maintaining human life. Without it, humans would perish from the Earth. Economical and plentiful food production in amounts sufficient to feed the world is only possible as a result of modern production agriculture. Greenhouse gas emissions from fertilizer application and soil management are a reality that cannot be overcome. Requiring food producers to report emissions would be cost prohibitive, and controlling such emissions is currently impossible. If there ever comes a day when sufficient quantities and types of food can be grown in economical and non-greenhouse gas producing ways, our producers would be interested in learning how to do so.

Preamble, Section IV.C. Rationale for Selection of Thresholds (p. 16469)

EPA is soliciting comments on how considerations of actual and potential emissions should be incorporated into the proposed threshold. We encourage EPA to maintain a focus on actual emissions estimates and not require facilities to calculate and report GHG emissions estimates based on a potential to emit. Potential emissions calculations would be extremely time consuming and expensive and would produce speculative results that would provide little useful, or worse, inaccurate information. Potential emissions are not relevant to climate change. Only actual emissions may be relevant. We believe that the methodologies outlined in the proposed rule allow facilities to enter site-specific and **actual** data to make an annual estimate of GHG emissions. We recommend EPA retain the approach outlined in the proposed rule.

Preamble, Section IV.C. Rationale for Selection of Thresholds (p. 16470)

EPA requests comments on other capacity thresholds that should be developed for different types of facilities and states that such comments should contain data and analysis to support the use of different thresholds. We would offer for EPA's consideration an alternative reporting threshold for manure management from open air beef cattle facilities of 54,436 MT CO_2e per year for reasons set forth below.

Throughout the proposal, EPA evaluated the number of facilities in every sector of the economy that would be required to report, with the majority of those facilities subject to a 25,000 MT CO_2e per year threshold. In the manure management analysis, EPA was presumably satisfied that 11 facilities at 88,923 head or larger would exceed the threshold and be required to report. **However**, the calculations provided to EPA by ERG, a long-time EPA contractor, were in error. After careful review of supporting materials for EPA's equations entitled "Beef Threshold_050109.xls," it became clear to TCFA that an error occurred as a result of ERG's failure to include a critical molecular weight conversion of N_2O-N to N_2O in its GHG calculations that resulted in its determination that only 11 cattle facilities would be required to report. The reality is that if EPA were to use the equation in the proposed rule, approximately 130 cattle facilities would be required to report. This number is approximately 12 times greater than EPA's estimated number. EPA's equation (corrected for N2O conversion factor and using ASABE data—see Attachment #4) shows that in order to meet its stated balance of "reporting" and "burden" on facilities the reporting threshold for manure management at open air beef cattle facilities would have to be increased to **54,436 MT CO_2e per year**. TCFA encourages the EPA to make this adjustment in an effort to enable the EPA to be consistent with the expressed intent of only subjecting 11 beef cattle facilities to the GHG mandatory reporting requirement.

Preamble, Section IV.C. Rationale for Selection of Thresholds (p. 16470)

EPA has proposed a "once in, always in" provision that would never allow a facility that has reduced emissions below the reporting threshold to no longer be subject to the annual reporting requirements. We are strongly opposed to this provision. Not allowing a facility to be rewarded for efforts to reduce GHG emissions would create a huge disincentive for undertaking such efforts. We recommend that EPA change the expensive and time consuming reporting obligation to require facilities to submit an initial report. If a facility continues to trigger the reporting threshold on an annual basis within a range that is not more than 25% of the initial estimate, no further annual actions should be required by the facility. If changes in production techniques or numbers of cattle in a facility are such that changes in GHG emissions would be more than 25% above initial estimates, then an annual report should be submitted for the year the change was made. Again, no subsequent reports should be required unless emission levels increase an additional 25% above the second report, and so on. Finally, and importantly, any facility that can document annual emissions that are less than the reporting threshold should be given the option of notifying EPA that they are no longer subject to the reporting requirement. To require otherwise would be to subject reporting facilities to needless and expensive regulatory burdens that provide little or no benefit to the EPA or society. Regulatory burdens should have important, real, and substantive regulatory purposes. Absent such purposes, regulation is inappropriate.

Preamble, Section IV.E. Rationale for Selecting the Reporting Year (p. 16470)

According to the proposal, the submission of the first "annual" report would be due March 1, 2011 to represent monitored, calculated, and quality assured data from Jan. 1, 2010 through Dec. 31, 2010. TCFA submits that this reporting timeframe is woefully unreasonable. It does not allow adequate time for businesses which have never submitted reports of this nature to understand, much less comply, with the regulations. In addition, given the volume of comments that EPA is likely to receive on this proposal and the need for serious discussion and/or reconsideration of numerous aspects of this rule, it is hard to imagine how EPA would be able adopt a final rule early enough in 2009 to allow affected facilities to initiate provisions required under it by Jan. 1, 2010. In fact, it is already too late this year for many facilities to prepare for and implement the requirements of this significant rulemaking. TCFA recommends that EPA at a minimum initiate the provisions of this rule <u>no sooner than two full calendar years</u> after the effective date of the final rule. For example, if EPA adopts the final rule in Nov. 2009, it would be appropriate for the initial monitoring year for this rule to commence on Jan. 1, 2012 and the first report would be due March 1, 2013. If EPA adopts the final rule in March 2010, the initial monitoring year would begin on Jan. 1, 2013 and the first annual report due March 1, 2014. If EPA adopts this rule at all, it is in the best interest of EPA and the facilities affected by the rule that all parties be given adequate time to fully study, prepare for, and implement the provisions in full compliance with the regulation. A reporting database created without the opportunity for due diligence will produce "garbage in – garbage out" results.

Preamble, Section IV.E.3 Recalculation and Missed Data (p. 16474)

The proposed rule requires that a facility's designated representative sign and date a certification statement which includes personal affirmation language and states that significant civil or criminal penalties may be imposed upon the designated representative for submitting false statements. TCFA urges EPA to recognize that even with a facility's best efforts reports may include inaccurate estimates or calculations which may need to be withdrawn or revised by the facility. Consequently, TCFA urges the EPA to recognize that changes in calculations, facility facts, and human errors do occur and provide an administrative process whereby a reporter would have an opportunity to submit voluntarily recalculated or missing data, or to provide updated reports based on new emissions estimating methodologies that may become available. This would provide EPA and the facilities affected by the rule with a means to create and maintain the most accurate database possible. Finally, a reporter should have the option to update any previously submitted report at any point in time that the reporter becomes aware of miscalculated, missing or updated emissions estimation methodologies that may become available. If such a revised report indicates that the reporter falls below the reporting threshold no additional reports should be required to be submitted, unless the reporter exceeds the threshold at some point in the future.

Preamble, Section IV.J.3. Selection of Self-Certification With EPA Verification as the Proposed Approach (p. 16477)

TCFA supports EPA's rationale for proposing a verification option that allows for self-certification of reports by affected facilities and verification provided by the EPA. We believe it is premature for EPA to establish a third party verification system for an emissions reporting program. The costs borne by the affected facilities will already be significant <u>new</u> costs. Any effort to layer-on third party verification will further exacerbate the costs incurred by producers and U.S. taxpayers.

Preamble, Section IV.K. Rationale for Selection of Duration of the Program (p. 16478)

The proposed rule requires the reporting of GHG emissions data on an ongoing, annual basis with no end in the future. TCFA submits that this proposal is unreasonable and that the program should expire and be reevaluated after a five-year period. This timeframe would be consistent with many EPA programs, permits, etc. that have an established "life" of five years. For example, NPDES permits issued under the Clean Water Act expire five years after the date of issuance; air permits under the auspices of the Clean Air Act are valid for five years; and the National Ambient Air Quality Standards must be reviewed every five years. It is difficult to identify any aspect of EPA's current programs that are developed and implemented over an infinite period of time. If the EPA decides upon reevaluation that more reporting should occur, additional rulemaking should be undertaken by EPA to continue the reporting program beyond an initial five year period. This approach would afford the public and affected facilities the opportunity to inform EPA of changes, modifications and corrections that may be needed at that point in time.

Preamble, Section V.B. Electricity Purchases (p. 16479)

While EPA has not proposed requiring facilities to report indirect GHG emissions through the consumption of electricity nor is the agency proposing to require that electricity purchases be reported, EPA is seeking comment on the value of collecting information on electricity purchases. TCFA is opposed to any effort by the EPA that would require a facility to report the amount of electricity purchased. First, we believe production-specific information is proprietary and confidential information that in the hands of competitors would provide them with an inside look at a facility's production efficiency. Second, there is no feasible method for EPA to determine the source of a particular kilowatt of power used by a single facility location that may be subject to this rule. We recommend that EPA not include any concept of requiring a facility to report electricity purchases/indirect GHG emissions in the final rule.

Preamble, Section V.JJ. Manure Management

Preamble, Section V.JJ.1. Definition of Source Category (p. 16561). TCFA submits several comments about this section.

First, the proposed rule states the following: "Anaerobic manure management systems include liquid/slurry handling in uncovered anaerobic lagoons, ponds, tanks, pits, or digesters." This sentence requires the reader to interpret that all "…ponds, tanks, pits…" are only components of anaerobic systems. In fact, "ponds, tanks, pits" may or may not be anaerobic depending on the design of the overall manure management system. We recommend that EPA separate the references to "ponds, tanks, pits" from "anaerobic manure management systems" since those systems' components may or may not be designed for anaerobic treatment of manure. For example, almost all ponds at beef cattle facilities across the U.S. are designed to be simple stormwater ponds used for temporary storage of rainfall prior to land application on adjacent cropland, pasture or rangeland. These stormwater ponds are typically aerobic and do not contain liquid manure. The contents of these ponds is predominantly water (99.5%+ moisture content) and is not considered slurry. Distinguishing aerobic systems used at open air beef cattle facilities from anaerobic systems used at other animal species systems is essential to accurately reflecting emission sources.

Second, TCFA is supportive of EPA's decision to limit the applicability of this reporting rule to the primary manure management system components of animal feeding operations. We agree with the statement, "The manure management system does not include other onsite units and processes at a livestock operation unrelated to the stabilization and/or storage of manure." As stated earlier, however, TCFA is perplexed about EPA's view of the point at which emissions from cattle manure become anthropogenic as opposed to natural. There is no unnatural process in an open air cattle feedyard situation. Cattle defecate and urinate. Manure falls to the ground. Natural biological processes occur that result in some GHG emissions. At some point the manure gets scraped from the feedyard floor, mounded, and eventually land applied as an organic fertilizer. Absent the scraping, this is the same process that occurs in manure found on pasture land. TCFA submits that GHG emissions from manure in a cattle feedyard are the result of natural, biological processes.

Third, TCFA agrees that if a final rule for mandatory reporting of GHG emissions is finalized and reports from manure management systems are required, EPA has appropriately identified CH_4 and N_2O as the constituents to be reported from a beef cattle manure management system (predominantly emissions from drylot and stormwater ponds). We agree with EPA's statements in the proposed rule, "Manure management also produces CO_2; however, this CO_2 is not counted in GHG totals as it is not considered an anthropogenic emission. Likewise, CO_2 resulting from the combustion of digester CH_4 is not counted as an anthropogenic emission under international accounting guidance."

Finally, as stated in other sections of these comments, there is good justification for EPA to include the statement, "This source category does not include systems which consist of only components classified as daily spread, solid storage, pasture/range/paddock, or manure composting." For equally compelling reasons, TCFA urges the EPA to expand these exclusions to cover similar components in typical cattle feeding facilities, and other unique situations, for the following reasons:

Daily spread – We recommend that EPA revise this definition to include "all land application of manure and stormwater." As outlined in these comments above, "there are no direct greenhouse gas emission measurement methods available except for research methods that are prohibitively expensive and require sophisticated equipment." The ability to obtain feasible facility-by-facility estimates of N_2O emissions from fields does not exist today. Consequently, EPA must clarify that the rule does not apply to any land application activities at beef cattle facilities.

Solid storage – Manure solids at beef cattle facilities are stored in a "dry" condition (typically in the range of 20-35% moisture content). Research conducted by West Texas A&M University (Attachment #6, unpublished) indicated very little methane production from dry manure storage; during cool months methane production was zero. As stated in the report, "Because most manure is stockpiled in open-lot animal feeding operations at less than 50 percent moisture content, it seems unlikely that methane will be produced from the stockpile."

Pasture/range/paddock – No beef facilities exist in the U.S. that would exceed the 25,000 MT CO_2e threshold. As proposed, EPA is correct to exclude these types of facilities from the proposed rule.

Manure composting – Very similar to EPA's current proposal that would create a "once in, always in" reporting paradigm, any effort to include manure composting operations would create a significant disincentive for further development and enhancement of manure composting operations in the U.S. We also recommend that EPA clarify the applicability of this exclusion to <u>all</u> manure composting entities/operations regardless of the proximity of the composting site to any facility that may be required to report under this rule.

Preamble, Section V.JJ.1. Definition of Source Category (p. 16562)

TCFA concurs with EPA's statement, "A facility that is subject to the proposed rule only because of emissions from manure management would also report CO_2, CH_4, and N_2O emissions from the combustion of supplemental fuel in flares using the methods in proposed 40 CFR part 98, subpart C, but would not be required to report any other combustion emissions." This statement maintains EPA's intent of reporting ONLY those GHG emissions relating to direct emissions from primary manure management system components—those components associated with the stabilization and/or storage of livestock manure.

Preamble, Section V.JJ.2. Selection of Reporting Threshold (p. 16562)

TCFA submits that any facility that implements technology to destroy carbon or convert GHGs with high global warming potential to those GHGs with a lower global warming potential should be allowed to account for the net carbon reduction in their GHG emissions estimates. Therefore, TCFA supports the "emissions threshold" approach, which takes into account and deducts CH_4 that is destroyed from the total CH_4 generation. Again, however, any cattle feeding operation that chooses or is able to expend the large amount of money necessary to utilize or install carbon reduction technologies resulting in emissions falling below the threshold level should no longer be required to report GHG emissions to the EPA. This should be one of the benefits of taking such actions.

Preamble, Section V.JJ.2. Table JJ-1 Estimated Head of Livestock To Meet Thresholds (p. 16562)

TCFA has carefully and thoroughly reviewed EPA's proposed farm size thresholds for beef cattle facilities. Based on this review; additional discussions with EPA and ERG on April 27, 2009; receipt of a follow-up email from Mr. Tom Wirth, EPA on May 4, 2009 with an attached updated Memo from Ms. Deborah Bartram, ERG dated May 4, 2009, TCFA has documented that EPA and ERG were way off the mark on the farm size threshold for beef cattle facilities that will be affected by this proposed rulemaking. The error is extreme. EPA's proposed beef cattle farm size threshold of 88,923 head one-time capacity is overstated by a factor of 1.7. A reporting threshold of 25,000 MT CO_2e per year would require approximately 130 beef cattle facilities to report emissions, not 11 beef cattle facilities suggested in the preamble by EPA. An error of this magnitude warrants republication of the proposed rule. EPA has led-astray a substantial number of facilities by implying that they would not be subject to this reporting rule and have very likely not engaged in this review and comment process. Without republication of the proposed rule, facilities that rationally assumed they were excluded from the provisions of this rule **WOULD** be subject to the final rule, if adopted as proposed. This is unacceptable. The only acceptable means of proceeding to a final rule, without republishing, is to establish a beef cattle facilities reporting threshold of 54,436 MT CO2e per year. At that level, an estimated 11 beef cattle facilities would be required to report—as originally proposed by EPA.

Errors in the calculations, assumptions, etc. are outlined below:

1. Upon receipt and review of the "Beef Threshold_050109.xls" received from ERG through EPA on May 4, 2009, it became apparent that a critical molecular weight conversion of N_2O-N to N_2O was not included. This conversion factor (44/28) is outlined in EPA's equations contained in the proposed rule; however, it was not applied in ERG's GHG calculations. This is a basic, yet critical, flaw in the emissions estimates and must be corrected.

2. Information provided to TCFA by ERG, the EPA contractor, indicates that it used a slightly different equation to estimate emissions from the equations EPA used in the proposed rule. The equation in the proposed rule uses "manure excretion rate" and separate percentages for "volatile solids" and "nitrogen content". However, the calculations provided by ERG include single values to represent a "volatile solids excretion rate" and a "nitrogen excretion rate." For the sake of clarity and transparency in the calculations, TCFA strongly urges the EPA to be consistent and use equations in the proposed rule that are backed up by supporting and supplementary documents provided by EPA and its contractors. Otherwise, any rationale behind equations proposed is suspect.

3. The source of data utilized by EPA and ERG for the following factors was the USDA-NRCS Animal Waste Management Field Handbook, 1992, Table 4-8. Please note the source data for many of the manure related data in this reference is 30+ years old. TCFA urges the EPA to use more accurate and up-to-date data.

In the early half of this decade, an extensive scientific effort was undertaken by multi-disciplinary team (engineers, animal scientists, nutritionists and others) including several land grant universities, USDA-NRCS, consultants, etc. to review and update the current state-of-the-science relative to animal manure production and characteristics. This effort culminated with the publication of a "Manure Production and Characteristics" standard by the American Society of Agricultural and Biological Engineers (ASABE), D384.2, March 2005 **(Attachment #5)**. For reasons set forth in later sections of these comments, TCFA urges the EPA to use this more accurate, up-to-date data.

The D384.2 ASABE standard includes Table 1. Section 3 – Estimated typical manure (urine and feces combined) characteristics as excreted by "Beef – Finishing cattle":

a. Manure excretion rate, using the equation for Dry Matter Excretion in Section 4.3.1 of ASABE D384.2,

$$DM_E = [DMI * (1-DMD/100)] + 20.3 * (0.06 * BW_{AVG}) =$$

65.1 kg manure/day/1,000 kg live animal mass

where,

Dry Matter Intake (DMI) = 2% of animal mass
Dry Matter Digestibility (DMD) = 80%
Body Weight Average (BW_{AVG}) = 446 kg
Excreted moisture content in Table 3a = 92%

b. Volatile solids (%, decimal, wet basis) = 290 kg divided by 4,500 kg total manure = 0.06444 (ASABE D384.2, Table 1a)

c. Nitrogen content (%, decimal, wet basis) = 25 kg divided by 4,500 kg total manure = 0.00556 (ASABE D384.2, Table 1a)

In addition, there is no need to differentiate between steers and heifers for volatile solids excretion rate or differing methane conversion factors for liquid/slurry. In the calculation worksheet provided by ERG, slightly different values were used for volatile solids and methane conversion factors for liquid/slurry. Current data does not support two different values for these input variables.

4. The EPA has assumed a value of 0.85% for the "fraction of VS entering liquid/slurry system with solids separation" and "fraction of N entering liquid/slurry system with solids separation." However, neither the proposed rule nor the additional information obtained from EPA or ERG provide the reference for this assumed value of 0.85%. If EPA adopts a final GHG mandatory reporting rule, we request that EPA provide the original source of all equations, values, assumptions, constants, variables, etc. used to determine the GHG emissions estimates.

5. ATTACHED is an Excel spreadsheet labeled "Manure Management – Beef Cattle Feedyard Estimates of Greenhouse Gases, May 2009" (Attachment #3) that includes all the updated assumptions and input variables listed above. The reference/source of all input data/assumptions are noted in parentheses to the right of each number.

Comparison of farm size thresholds (one-time capacity) among calculated estimates:

Federal Register	**Attachment #1**	**Attachment #2**	**Attachment #3**	**Attachment #4**
EPA Proposed Rule (4/10/2009)	EPA/ERG Revisions (5/4/2009 Memo)	Corrected Estimate – Industry calcs. using EPA method – Includes N_2O-N to N_2O conversion (5/7/2009)	Industry Estimate Using Best Available Input Data – ASABE D384.2 MAR2005 (5/28/2009) **25,000 MT CO_2e**	Industry Estimate Using Best Available Input Data – ASABE D384.2 MAR2005 (5/28/2009) **54,436 MT CO_2e**
89,000 head (supporting docs. indicate 88,923 head)	**78,068 head**	**51,688 head**	**40,839 head**	**88,923 head**

Additional correction and updates to EPA's equation (corrected for N2O conversion factor and using ASABE data—see Attachment #4) shows that in order to meet its stated balance of "reporting" and "burden" on facilities the reporting threshold for manure management at open air beef cattle facilities would have to be increased to **54,436 MT CO_2e per year**. TCFA encourages the EPA to make this adjustment in an effort to enable the EPA to be consistent with the expressed intent of only subjecting **11 beef cattle facilities** with a one-time capacity of **88,923 head** to the GHG mandatory reporting requirement.

TCFA strongly recommends that EPA clearly state in the final rule that any beef cattle facility with a drylot and stormwater pond manure management system that maintains (on an annual daily average) an inventory of cattle that is 88,923 head or less IS NOT subject to the provisions of this GHG emissions mandatory reporting rule. This would eliminate the need for those facilities with 88,923 head or less to analyze monthly manure samples for volatile solids and nitrogen, calculate emissions at the end of a calendar year, and prevent them from expending valuable time and resources to re-verify an emissions threshold estimate that has already been calculated and published in the final rule.

Preamble, Section V.JJ.3. Selection of Proposed Monitoring Methods (p. 16563)

EPA is seeking comment on the option of using facility-specific livestock population and mass, and default values for volatile solids rate to estimate total volatile solids, instead of measured values. EPA is also seeking comment on whether a different sampling and testing frequency, such as quarterly, would be more appropriate than monthly. First, we believe it is imperative that a facility be allowed to use site specific population and average animal mass data. The base input variables for the CH_4 and N_2O emissions estimating methodologies are animal population and mass. Site specific values for these two inputs is important. Second, given the recent significant undertaking of the scientific community to update volatile solids data in ASABE D384.2, we would contend that is appropriate for default values to be used for volatile solids. Third, we would support EPA allowing producers the option of (1) using default look-up values or (2) using facility, site-specific data.

We also recommend that EPA define "freshly excreted" manure to be manure that is a composite sample and representative of manure and urine excreted that is not more than three days old. This manure would be characteristically similar to the manure collected and utilized in the study by Hashimoto in 1981.

Finally, the maximum methane potential values (B_0) was obtained from a study conducted by Hashimoto in 1981. A copy of the research article was provided by EPA on May 4, 2009. Based on more recent research knowledge obtained on manure and associated air quality measurements, we would appreciate an EPA response to the concerns/questions with this research study conducted 28 years ago:

1. Are the feed rations used by Hashimoto in 1981 representative of current rations used in beef cattle production?
2. The fermenters were modified with baffles "glued" to the side of the containers. What type of glue was used and what effect would it have on measurement of gaseous emissions using Tedlar bags?
3. The fermenter/slurry manure process utilized by Hashimoto (i.e., initial solids content of 14 %, further diluted to 10%) does not represent the storage practice of manure in modern beef cattle production (i.e., manure solids content in drylots of 60-80%). This methodology appears to greatly overestimate any real-world conditions for maximum methane potential. Please explain.
4. The study refers to the addition of "inoculum." What was the inoculum?
5. Is the Packard Model 428 gas chromatograph still in use today? If not, has a comparative study to modern gas measurement techniques been conducted to validate the gas concentrations that would have been measured in 1981?
6. The study by Hashimoto utilized a target slaughter weight of "weighing over 400 kg." Cattle today are fed to target slaughter weights of 520 to 590 kg. As such, the data collected in 1981 is not representative of current production practices.

Preamble, Section V.JJ.3. Selection of Proposed Monitoring Methods (p. 16563)

EPA is requesting comment on considering developing a tool to assist reporters in calculating emissions from this source category, such as EPA's FarmWare and CCAR's Livestock Project Reporting Protocol. TCFA is not opposed to the development of a tool that would be available to producers for making these estimates of emissions; however, we are opposed to the examples provided in the proposed rule for the following reasons.

1. FarmWare is not applicable to beef cattle facilities. FarmWare is an analytical tool designed to provide a preliminary assessment on the benefits of integrating anaerobic digestion into an existing or planned dairy or swine manure management system. In addition, according to EPA's website (5/29/09), FarmWare is being revised and temporarily is unavailable. Open air beef cattle facilities are very different from dairy or swine operations, including the fact that they do not use anaerobic digestion systems for manure management. Any tool that is developed must be appropriate for and differentiated among animal species.

2. The California Climate Action Registry -- Livestock Management Project Reporting Protocol is focused on capturing and combusting methane from manure management systems. Since there is very little proven technology available to beef cattle facilities to capture and combust methane from dry manure, the CCAR—Livestock Management Project Reporting Protocol is not applicable to beef cattle facilities.

Statement of Comment Applicability to Sections of Proposed Rule Language

> To minimize redundancy, efficiency of comment review and limit the pages of comments filed, TCFA requests that EPA consider all of the comments stated above on the preamble language to also be applicable to the corresponding section of the proposed rule language.

Additional Comments on Specific Sections of the Proposed Rule Language, not Previously Commented on in the Preamble

Proposed Rule, Section 98.364(a) (p. 16708)

> EPA has proposed a requirement to "Perform a one-time analysis on your operation to determine the percent of total manure by weight that is managed in each on-site manure management system." For open air beef cattle facilities, this is requirement cannot be met. The hydrology of a feedyard is very complex and can only be evaluated in laboratory or small-scale field studies, such as research locations with discrete drainage that can be quantified using flumes or other measuring devices. TCFA recommends that EPA delete this site-specific requirement and permit a facility to use research data or other published information to determine the percent of manure handled in each on-site manure management system.

Proposed Rule, Section 98.364(a) (p. 16708)

> In reference to laboratory analyses of manure, the proposed rule states, "The laboratory performing the analyses should be certified for analysis of waste for National Pollutant Discharge Elimination System compliance reporting." To our knowledge, EPA does not maintain a list of laboratories that are certified for NPDES compliance reporting. TCFA requests that EPA clarify what is meant by this statement in the proposed rule.

TCFA appreciates the opportunity to submit comments on the proposed rule for mandatory reporting of greenhouse gases.

Sincerely,

Ross Wilson

Ross Wilson
President & CEO

ATTACHMENT #1

MEMORANDUM

TO: Melissa Weitz, EPA
Tom Wirth, EPA

FROM: Deb Bartram, ERG
Cortney Itle, ERG

DATE: 4 May 2009

SUBJECT: ***Contract EP-W-07-067, Task Order 18***
Response to NCBA/TCFA Questions on GHG Reporting Rule: Manure

At EPA's request, ERG participated in a teleconference with EPA, Texas Cattle Feeders Association (TCFA), and National Cattleman's Beef Association (NCBA). The purpose of the meeting was to discuss assumptions and methods used to make the calculations in the proposed GHG Reporting Rule as it applies to cattle feedlots. This memorandum presents a list of attendees in the call (see Table 1), questions raised by participants on the call, and ERG's responses to questions. In addition, ERG presents a summary of the specific threshold calculation for cattle feedlots, including the assumptions and constants used.

Table 1. List of Conference Call Participants

Name	Affiliation	Email
Ben Weinheimer	TCFA	ben@tcfa.org
Tom McDonald	TCFA	Tom.mcdonald@fiveriverscattle.com
Tamara Thies	NCBA	tthies@beef.org
Melissa Weitz	EPA Office of Atmospheric Programs	Weitz.melissa@epa.gov
Tom Wirth	EPA Office of Atmospheric Programs	Wirth.tom@epa.gov
Larry Elmore	EPA Office of Air Quality Planning and Standards	Elmore.larry@epa.gov
Bill Schrock	EPA Office of Air Quality Planning and Standards	Schrock.bill@epa.gov
Deb Bartram	Eastern Research Group	Deborah.bartram@erg.com

Cattle Feedlot Threshold Calculation

EPA prepared two threshold calculations for beef operations: 1) beef cattle managed in pastures and 2) beef feedlots. All manure excreted by beef cattle at a feedlot is assumed to be deposited in a drylot and have the potential to generate greenhouse gas emissions during the time the manure is stacked or stored in the feedlot pens. In addition, EPA estimates that a small amount of manure is transported off the drylot area into a runoff pond, and has further potential to generate greenhouse gases in this liquid storage. The amount of runoff from feedlots was calculated using an average value for the entire U.S.

EPA first assumed the distribution of heifer and steer population on a feedlot was equal to the overall U.S. distribution of cattle on feed. From EPA's U.S. Inventory for Greenhouse Gas Emissions and Sinks (2006), ERG estimated that 65% of feedlot cattle are steer and 35% are heifers. The greenhouse gas emissions for each population were estimated as:

$$\text{GHG}_{\text{cattle type}} = \text{Drylot Emissions}_{\text{cattle type}} + \text{Runoff Pond Emissions}_{\text{cattle type}}$$

Drylot and runoff pond emissions for each cattle type were calculated as:

$$\text{Emissions}_{\text{cattle type, system}} = \text{Methane}_{\text{cattle type, system}} + \text{Nitrous Oxide}_{\text{cattle type, system}}$$

$$\text{Methane}_{\text{cattle type, system}} = \text{Population x TAM x VS} \div 1000 \text{ x Bo x MCF x density x Days/yr}$$

$$\text{Nitrous Oxide}_{\text{cattle type, system}} = \text{Population x TAM x N} \div 1000 \text{ x EF x Days/yr}$$

Where,

TAM = typical animal mass (420 kg for both heifer and steer)
VS = volatile solids excretion rate, kg VS/day/1,000 kg animal (3.579 for heifer; 3.551 for steer)
N = nitrogen excretion rate, kg N/day/1000 kg animal (0.3 for both heifer and steer)
Bo = maximum methane producing potential, m^3 CH_4/kg VS (0.33 for both heifer and steer)
MCF = average U.S. methane conversion factor from EPA's 2006 GHG Inventory (0.0114 for both heifer and steer drylots; 0.304 for heifer runoff ponds; 0.287 for steer runoff ponds)
EF = N_2O emission factor (0.02 for drylot; 0.005 for runoff pond)
Density= 0.662 kg CH_4/m^3 CH_4
Days = 365.25 average days/year

Using these equations, and correcting a cell reference in the proposed rule calculations, ERG calculates that a feedlot population of **78,068** head (65% steer, 35% heifer) will meet the 25,000 tCO_2eq threshold. See the Excel file entitled *Beef Threshold_050109.xls* for more information.

Specific Questions on EPA's Threshold Calculations

1. Provide the source of the manure excretion rates used in the calculation.

EPA's threshold calculations are completed on a national level using reference excretion values for volatile solids and nitrogen. Therefore, the manure excretion rate is not used directly in the threshold calculation. However, the source for the value, which is to be used with site-specific measurements of VS and N excretion, is the USDA *Animal Waste Management Field Handbook*, 1992, Table 4-8. ERG used the value for a feeder, yearling (750 to 1,100 lb) on a high energy diet.

2. Provide the source of % volatile solids used in the calculation.

The % VS used in the national threshold calculation comes from EPA's 2006 Cattle Enteric Fermentation Model (CEFM).

3. For the % runoff calculation provide the sources used in the calculation.

As part of EPA's annual GHG Inventory, ERG calculates regional runoff values based on the methodology established by EPA's Office of Water during the development of effluent guidelines for concentrated animal feeding operations. See EPA's *Cost Methodology for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations*. U.S. Environmental Protection Agency. EPA-821-R-03-004. December 2002.

For the GHG reporting rule threshold, ERG used an average U.S. runoff value calculated from the 2006 U.S. Inventory.

4. For the maximum methane production potential, Bo, provide the source for the value of 0.33.

The source for this value is Hashimoto, A.G., V.H. Varel, and Y.R. Chen (1981) "Ultimate Methane Yield from Beef Cattle Manure; Effect of Temperature, Ration Constituents, Antibiotics and Manure Age." *Agricultural Wastes,* 3:241-256.

5. Provide the source of the % N in manure that is used in the N2O calculation.

The source for this value is the USDA *Animal Waste Management Field Handbook*, 1992, Table 4-8. ERG used the value for a feeder, yearling (750 to 1,100 lb) on a high energy diet.

6. Provide the animal live weights and their source used in the calculations.

The following live weights and their source were used for the various cattle populations:

Cattle Type	Typical Animal Mass (TAM)	Source for TAM
Feedlot Cattle		
Heifer	420	AWMFH, Table 4-8, average weight of feeder cattle.
Steer	420	AWMFH, Table 4-8, average weight of feeder cattle.
Cattle Not on Feed		
Bull	750	Safley 2000. Telephone conversation between Deb Bartram of ERG and L.M. Safley, President, Agri-Waste Technology. June and October 2000.
Calf	118	USDA, Lander, 1998. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements
Cow	533	Safley 2000. Telephone conversation between Deb Bartram of ERG and L.M. Safley, President, Agri-Waste Technology. June and October 2000.
Heifer	420	Safley 2000. Telephone conversation between Deb Bartram of ERG and L.M. Safley, President, Agri-Waste Technology. June and October 2000.
Steer	318	Safley 2000. Telephone conversation between Deb Bartram of ERG and L.M. Safley, President, Agri-Waste Technology. June and October 2000.

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

Manure Management -- Beef Cattle Feedyard Estimates
Corrected Estimate - Industry Calculations Using EPA Method - To include Proper Conversion from N2O-N to N2O

Total one-time capacity of feedyard (steers + heifers): **51688** head

STEERS

Number of Head (average annual one-time capacity):	**33390**	head steers			(Source: EPA assumption of 64.6% steers)
Average Cattle Weight (pounds):	**923**	pounds	**420**	kg	(Source: EPA assumption in Table JJ-1)
Manure Excretion Rate (kg/day/1000 kg liveweight):	**51.2**	kg/day/1000 kg live			(Source: AWMFH, 1992, Table 4-8)
Percent Volatile Solids (decimal w.b.):	**0.069355**	decimal w.b.			(Source: EPA CEFM, 2006) VS excretion rate = 3.551
Distribution of VS at feedyard:					
Drylot:	**100**	%			
Pond:	**0.85**	%			(Source: Avg. U.S. runoff value, 2006 U.S. Inv.)
Maximum Methane Potential (Bo) (m3 CH4/kg VS):	**0.33**	m3 CH4/kg VS			(Source: Hashimoto, 1981)
Methane Conversion Factor (**assumes highest temperature on Table JJ-2**):					
Drylot:	**0.0114**	decimal %			(Source: 2006 U.S. Inv.)
Pond (Liquid/slurry w/o crust):	**0.287**	decimal %			(Source: 2006 U.S. Inv., steers)
Percent Total Nitrogen in Manure:	**0.00586**	decimal w.b.			(Source: AWMFH, 1992, Table 4-8) N excretion rate = 0.3

METHANE (STEERS)

Total Volatile Solids = %VS x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 49,745 kg/day

CH4 = [TVS x VS manure mngt distribution x 365.25 x Max CH4 potential x CH4 conversion factor] * 0.662 =

Drylot = 45,250 kg/year
Pond = 9,683 kg/year

Total CH4 Produced = 54,933 kg/year

Carbon Dioxide Equivalent of Methane Produced =
Total CH4 Produced x 1/1000 x 21 = 1,154 **Metric Tons / year of CO2eq from CH4**

HEIFERS

Number of Head (average annual one-time capacity):	**18298**	head heifers			(Source: EPA assumption of 35.4% heifers)
Average Cattle Weight (pounds):	**923**	pounds	**420**	kg	(Source: EPA assumption in Table JJ-1)
Manure Excretion Rate (kg/day/1000 kg liveweight):	**51.2**	kg/day/1000 kg live			(Source: AWMFH, 1992, Table 4-8)
Percent Volatile Solids (decimal w.b.):	**0.069902**	decimal w.b.			(Source: EPA CEFM, 2006) VS excretion rate = 3.579
Distribution of VS at feedyard:					
Drylot:	**100**	%			
Pond:	**0.85**	%			(Source: Avg. U.S. runoff value, 2006 U.S. Inv.)
Maximum Methane Potential (Bo) (m3 CH4/kg VS):	**0.33**	m3 CH4/kg VS			(Source: Hashimoto, 1981)
Methane Conversion Factor (**assumes highest temperature on Table JJ-2**):					
Drylot:	**0.0114**	decimal %			(Source: 2006 U.S. Inv.)
Pond (Liquid/slurry w/o crust):	**0.304**	decimal %			(Source: 2006 U.S. Inv., heifers)
Percent Total Nitrogen in Manure:	**0.00586**	decimal w.b.			(Source: AWMFH, 1992, Table 4-8) N excretion rate = 0.3

METHANE (HEIFERS)

Total Volatile Solids = %VS x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 27,475 kg/day

CH4 = [TVS x VS manure mngt distribution x 365.25 x Max CH4 potential x CH4 conversion factor] * 0.662 =

Drylot = 24,992 kg/year
Pond = 5,665 kg/year

Total CH4 Produced = 30,657 kg/year

Carbon Dioxide Equivalent of Methane Produced =
Total CH4 Produced x 1/1000 x 21 = 644 **Metric Tons / year of CO2eq from CH4**

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

Manure Management -- Beef Cattle Feedyard Estimates

Corrected Estimate - Industry Calculations Using EPA Method - To include Proper Conversion from N2O-N to N2O

NITROUS OXIDE (STEERS)

N excreted = Nitrogen in manure x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 4,203 kg/day

N2O emissions = (N excreted x % by manure mngt distribution x Emission factor by type x 365.25) * 44/28 =

Emission factor by type (kg N2O-N/kg Kjdl N):

Drylot:	0.02	Drylot =	48,248	kg/year
Pond:	0.005	Pond =	103	kg/year

Total N2O Produced = 48,351 kg/year

Carbon Dioxide Equivalent of Nitrous Oxide Produced =
Total N2O Produced x 1/1000 x 310 = **14,989 Metric Tons / year of CO2eq from N2O**

TOTAL ESTIMATE OF GREENHOUSE GAS EMISSIONS (CH4 + N2O)

Methane (CO2eq) = 1,154 kg/year

Nitrous Oxide (CO2eq) = 14,989 kg/year

TOTAL CO2eq Emissions = 16,142 Metric Tons / yr CO2eq from CH4 + N2O

NITROUS OXIDE (HEIFERS)

N excreted = Nitrogen in manure x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 2,303 kg/day

N2O emissions = (N excreted x % by manure mngt distribution x Emission factor by type x 365.25) * 44/28 =

Emission factor by type (kg N2O-N/kg Kjdl N):

Drylot:	0.02	Drylot =	26,440	kg/year
Pond:	0.005	Pond =	56	kg/year

Total N2O Produced = 26,496 kg/year

Carbon Dioxide Equivalent of Nitrous Oxide Produced =
Total N2O Produced x 1/1000 x 310 = **8,214 Metric Tons / year of CO2eq from N2O**

TOTAL ESTIMATE OF GREENHOUSE GAS EMISSIONS (CH4 + N2O)

Methane (CO2eq) = 644 kg/year

Nitrous Oxide (CO2eq) = 8,214 kg/year

TOTAL CO2eq Emissions = 8,857 Metric Tons / yr CO2eq from CH4 + N2O

Methane Grand Total (Steers+Heifers) = 1,797 Metric Tons / yr CO2eq from CH4

Nitrous Oxide Grand Total (S+H) = 23,202 Metric Tons / yr CO2eq from N2O

GRAND TOTAL of STEER + HEIFERS = 25,000 Metric Tons / yr CO2eq from CH4 + N2O

Attachment #3 5/28/09

Manure Management -- Beef Cattle Feedyard Estimates to meet 25,000 MT CO2e Threshold

Industry Estimate Using Best Available Input Data - ASABE D384.2 MAR2005

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

Number of Head (average annual one-time capacity):	**40839**	head			
Average Cattle Weight (pounds):	**981**	pounds	**446**	kg	(Source: ASABE D384.2, MAR2005, Table 3b)
Manure Excretion Rate (kg/day/1000 kg liveweight):	**65.1**	kg/day/1000 kg live			(Source: ASABE D384.2, MAR2005, Section 4.3.1 eq. where DMI=2%, DMD=80% and BWavg=446 kg)
Percent Volatile Solids (decimal w.b.):	**0.064440**	decimal w.b.			(Source: ASABE D384.2, MAR2005, Table 1a)
Distribution of VS at feedyard:					
Drylot:	**100**	%			
Pond:	**0.85**	%			(Source: Avg. U.S. runoff value, 2006 U.S. Inv.)
Maximum Methane Potential (Bo) (m3 CH4/kg VS):	**0.33**	m3 CH4/kg VS			(Source: Hashimoto, 1981)
Methane Conversion Factor (**assumes highest temperature on Table JJ-2**):					
Drylot:	**0.01**	decimal %			(Source: 2008 Avg. U.S. Temp. 11.7^{o} C & Table JJ-2)
Pond (Liquid/slurry w/o crust):	**0.197**	decimal %			(Source: 2008 Avg. U.S. Temp. 11.7^{o} C & Table JJ-2)
Percent Total Nitrogen in Manure:	**0.00556**	decimal w.b.			(Source: ASABE D384.2, MAR2005, Table 1a)

METHANE

Total Volatile Solids = %VS x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 76,394 kg/day

CH4 = [TVS x VS manure mngt distribution x 365.25 x Max CH4 potential x CH4 conversion factor] * 0.662 =

Drylot = 60,957 kg/year
Pond = 10,207 kg/year

Total CH4 Produced = 71,164 kg/year

Carbon Dioxide Equivalent of Methane Produced =
Total CH4 Produced x 1/1000 x 21 = **1,494** **Metric Tons / year of CO2eq from CH4**

Manure Management -- Beef Cattle Feedyard Estimates to meet 25,000 MT CO2e Threshold

Industry Estimate Using Best Available Input Data - ASABE D384.2 MAR2005

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

NITROUS OXIDE

N excreted = Nitrogen in manure x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 6,591 kg/day

N2O emissions = (N excreted x % by manure mngt distribution x Emission factor by type x 365.25) * 44/28 =

Emission factor by type (kg N2O-N/kg Kjdl N):

Drylot:	0.02	Drylot =	75,664 kg/year
Pond:	0.005	Pond =	161 kg/year

Total N2O Produced = 75,825 kg/year

Carbon Dioxide Equivalent of Nitrous Oxide Produced =
Total N2O Produced x 1/1000 x 310 = 23,506 Metric Tons / year of CO2eq from N2O

TOTAL ESTIMATE OF GREENHOUSE GAS EMISSIONS (CH4 + N2O)

Methane (CO2eq) = 1,494 kg/year

Nitrous Oxide (CO2eq) = 23,506 kg/year

TOTAL CO2eq Emissions = 25,000 Metric Tons / yr CO2eq from CH4 + N2O

Manure Management -- Beef Cattle Feedyard Estimates for 88,923 head as Proposed by EPA

Industry Estimate Using Best Available Input Data - ASABE D384.2 MAR2005

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

Number of Head (average annual one-time capacity):	**88923**	head			
Average Cattle Weight (pounds):	**981**	pounds	**446**	kg	(Source: ASABE D384.2, MAR2005, Table 3b)
Manure Excretion Rate (kg/day/1000 kg liveweight):	**65.1**	kg/day/1000 kg live			(Source: ASABE D384.2, MAR2005, Section 4.3.1 eq. where DMI=2%, DMD=80% and BWavg=446 kg)
Percent Volatile Solids (decimal w.b.):	**0.064440**	decimal w.b.			(Source: ASABE D384.2, MAR2005, Table 1a)
Distribution of VS at feedyard:					
Drylot:	**100**	%			
Pond:	**0.85**	%			(Source: Avg. U.S. runoff value, 2006 U.S. Inv.)
Maximum Methane Potential (Bo) (m3 CH4/kg VS):	**0.33**	m3 CH4/kg VS			(Source: Hashimoto, 1981)
Methane Conversion Factor (**assumes highest temperature on Table JJ-2**):					
Drylot:	**0.01**	decimal %			(Source: 2008 Avg. U.S. Temp. 11.7° C & Table JJ-2)
Pond (Liquid/slurry w/o crust):	**0.197**	decimal %			(Source: 2008 Avg. U.S. Temp. 11.7° C & Table JJ-2)
Percent Total Nitrogen in Manure:	**0.00556**	decimal w.b.			(Source: ASABE D384.2, MAR2005, Table 1a)

METHANE

Total Volatile Solids = %VS x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 166,340 kg/day

CH4 = [TVS x VS manure mngt distribution x 365.25 x Max CH4 potential x CH4 conversion factor] * 0.662 =

Drylot = 132,727 kg/year
Pond = 22,225 kg/year

Total CH4 Produced = 154,952 kg/year

Carbon Dioxide Equivalent of Methane Produced =
Total CH4 Produced x 1/1000 x 21 = **3,254** **Metric Tons / year of CO2eq from CH4**

Manure Management -- Beef Cattle Feedyard Estimates for 88,923 head as Proposed by EPA

Industry Estimate Using Best Available Input Data - ASABE D384.2 MAR2005

EPA Proposed Rule--Mandatory Reporting of Greenhouse Gases (Federal Register 4/10/2009)

NITROUS OXIDE

N excreted = Nitrogen in manure x (Number of Head x Average cattle weight x Manure excretion rate/1000) = 14,352 kg/day

N2O emissions = (N excreted x % by manure mngt distribution x Emission factor by type x 365.25) * 44/28 =

Emission factor by type (kg N2O-N/kg Kjdl N):

Drylot:	0.02	Drylot =	164,752	kg/year
Pond:	0.005	Pond =	350	kg/year
		Total N2O Produced =	165,102	kg/year

Carbon Dioxide Equivalent of Nitrous Oxide Produced =

Total N2O Produced x 1/1000 x 310 = 51,182 Metric Tons / year of CO2eq from N2O

TOTAL ESTIMATE OF GREENHOUSE GAS EMISSIONS (CH4 + N2O)

Methane (CO2eq) =	3,254	kg/year
Nitrous Oxide (CO2eq) =	51,182	kg/year
TOTAL CO2eq Emissions =	**54,436**	**Metric Tons / yr CO2eq from CH4 + N2O**

ATTACHMENT #5

ASAE D384.2 MAR2005
Manure Production and Characteristics

American Society of
Agricultural and Biological Engineers

STANDARD

ASABE is a professional and technical organization, of members worldwide, who are dedicated to advancement of engineering applicable to agricultural, food, and biological systems. ASABE Standards are consensus documents developed and adopted by the American Society of Agricultural and Biological Engineers to meet standardization needs within the scope of the Society; principally agricultural field equipment, farmstead equipment, structures, soil and water resource management, turf and landscape equipment, forest engineering, food and process engineering, electric power applications, plant and animal environment, and waste management.

NOTE: ASABE Standards, Engineering Practices, and Data are informational and advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. The ASABE assumes no responsibility for results attributable to the application of ASABE Standards, Engineering Practices, and Data. Conformity does not ensure compliance with applicable ordinances, laws and regulations. Prospective users are responsible for protecting themselves against liability for infringement of patents.

ASABE Standards, Engineering Practices, and Data initially approved prior to the society name change in July of 2005 are designated as ‘ASAE’, regardless of the revision approval date. Newly developed Standards, Engineering Practices and Data approved after July of 2005 are designated as ‘ASABE’.

Standards designated as ‘ANSI’ are American National Standards as are all ISO adoptions published by ASABE. Adoption as an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria for approval have been met by ASABE.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

CAUTION NOTICE: ASABE and ANSI standards may be revised or withdrawn at any time. Additionally, procedures of ASABE require that action be taken periodically to reaffirm, revise, or withdraw each standard.

ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA ph. 269-429-0300, fax 269-429-3852, hq@asabe.org

ASAE D384.2 MAR2005

Manure Production and Characteristics

Developed by the Engineering Practices Subcommittee of the ASAE Agricultural Sanitation and Waste Management Committee; approved by the Structures and Environment Division Standards Committee; adopted by ASAE December 1976; reconfirmed December 1981, December 1982, December 1983, December 1984, December 1985, December 1986, December 1987; revised June 1988; revised editorially and reaffirmed December 1993; revised editorially March 1995; reaffirmed December 1998, December 1999, December 2001, February 2003; revised March 2005 by a joint committee of ASAE and Federation of Animal Science Societies members.

1.0 Purpose

1.1 This standard provides three types of information for estimating characteristics of livestock and poultry manure:

- Typical characteristics for manure "as-excreted" by livestock and poultry based on typical diets and animal performance levels in 2002 (Section 3);
- Equations for estimating manure excretion characteristics based on animal performance and dietary feed and nutrient intake specific to an individual situation (Sections 4 through 9);
- Typical characteristics for manure "as-removed" from manure storage or animal housing (Section 10).

1.2 Typical or average estimates of manure excreted become obsolete due to changes in animal genetics, performance potential, feeding program strategies, and available feeds. To minimize future concerns, a set of equations for predicting nutrient excretion (primarily nitrogen and phosphorus), dry matter, and, depending upon species, other potential characteristics have been assembled for beef, dairy, swine, horses and poultry. The Equation Estimates sections (Sections 4 through 9) allow an estimate of manure characteristics that is relevant to a wide range of dietary options and animal performance levels commonly observed in commercial production.

1.3 It is more appropriate to use the equations in Sections 4 through 9 for the following situations:

- When comprehensive nutrient management plans are being developed specific to an individual animal feeding operation (AFO);
- When farm specific data is available for an AFO's feeding program and animal performance;
- When feed intake, feed nutrient concentration, feed digestibility, or animal performance varies from the assumptions used to estimate the typical values in Table 1.
- When Table 1 has not been updated to address industry trends.

1.4 It may be more appropriate to use the typical values found in Table 1 for the following situations:

- When planning estimates are being made on a scale larger than a single farm (e.g. county or regional estimate of nutrient excretion)
- When a rough approximation is needed for farm planning;
- When farm-specific information of animal performance and feed intake is not available.

2.0 Caution

2.1 Section 3. Typical As-Excreted Manure Production and Characteristics. The user of these data should recognize that the reported typical values may become obsolete with time due to changes in animal genetics, feeding programs, alternative feeding technologies, and available feeds. In addition, users should also recognize that under current conditions, excretion of nutrients and other related characteristics will vary for individual situations from the currently listed values due to variations in animal feed nutrient intake, animal performance, and individual farm management. Sections 4 – 9 provide an alternative, and often more accurate, methodology for estimating nutrient excretion for individual production systems.

Table 1. Section 3 – Estimated typical manure (urine and feces combined) characteristics as excreted[1] by:

Table 1.a – Meat-producing livestock and poultry. Diet based numbers are in **BOLD.** See footnotes 2 and 3 for source of non-bold values.

Animal Type and Production Grouping	Total solids[3]	Volatile solids[3]	COD[3,4]	BOD[3,4]	Nitrogen	P	K	Ca	Total Manure[5]		Moisture[6]	Assumed Finishing Time Period (days)
	kg / finished animal (f.a.)								kg / f.a.	liter / f.a.	% w.b.	
Beef - Finishing cattle	**360**	**290**	300	67	**25**	**3.3**	17.1	**7.7**	4,500	4,500	92	153
Poultry - Broiler	**1.3**	0.95	1.05	0.30	**0.053**	**0.016**	**0.031**		4.9	4.9	74	48
Poultry - Turkey (male)	**9.2**	7.4	8.5	2.4	**0.55**	**0.16**	0.26		36	36	74	133
Poultry - Turkey (females)	**4.4**	3.5	4.0	1.1	**0.26**	**0.074**	0.11		17	17	74	105
Poultry - Duck	**1.7**	1.0	1.4	0.28	**0.062**	**0.022**	0.031		6.5	6.5	74	39
Swine - Nursery pig (12.5 kg)	4.8	4.0	4.4	1.5	**0.41**	**0.068**	0.16		48	48	90	36
Swine - Grow-finish (70 kg)	**56**	45	47	17	**4.7**	**0.76**	2.0		560	560	90	120
	lb / finished animal (f.a.)									ft^3 / f.a.	% w.b.	
Beef - Finishing cattle	**780**	**640**	670	150	**55**	**7.3**	38	**17**	9,800	160	92	153
Poultry - Broiler	**2.8**	2.1	2.3	0.66	**0.12**	**0.035**	**0.068**		11	0.17	74	48
Poultry - Turkey (male)	**20**	16	19	5.2	**1.2**	**0.36**	0.57		78	1.3	74	133
Poultry - Turkey (females)	**9.8**	7.8	8.8	2.4	**0.57**	**0.16**	0.25		38	0.61	74	105
Poultry - Duck	**3.7**	2.2	3.0	0.61	**0.14**	**0.048**	0.068		14	0.23	74	39
Swine - Nursery pig (27.5 lb)	10	8.7	9.7	3.4	**0.91**	**0.15**	0.35		87	1.4	90	36
Swine - Grow-finish (154 lb)	**120**	99	104	38	**10**	**1.7**	4.4		1200	20	90	120

Table 1.b – Section 3 – All other livestock and poultry. Diet based numbers are in **BOLD.** See footnotes 2 and 3 for source of non-bold values.

Animal Type and Production Grouping	Total solids[3]	Volatile solids[3]	COD[3,4]	BOD[3,4]	Nitrogen	P	K	Ca	Mg	Total Manure[5]		Moisture[6]
	kg / day-animal (d-a)									kg / (d-a)	liter / d-a.	% w.b.
Beef - Cow (confinement)[7,10]	**6.6**	**5.9**	6.2	1.4	**0.19**	**0.044**	0.14	**0.089**		-	-	88
Beef - Growing Calf (confinement)	**2.7**	**2.3**	2.3	0.52	**0.13**	**0.025**	0.085	**0.040**		22	22	88
Dairy - Lactating cow	**8.9**	7.5	8.1	1.30	**0.45**	**0.078**	**0.103**			68	68	87
Dairy - Dry cow	**4.9**	4.2	4.4	0.626	**0.23**	0.03	0.148			38	3	87
Dairy - Milk fed calves					0.0079							
Dairy - Calf-150 kg	1.4				0.063					8.5	8.5	83
Dairy - Heifer-440 kg	3.7	3.2	3.4	0.54	**0.12**	**0.020**				22	22	83
Dairy - Veal-118 kg	0.12				0.015	0.0045	0.0199			3.5	3.5	96
Horse - Sedentary-500 kg[8]	**3.8**	3.0		0.48	**0.089**	**0.013**	**0.027**	**0.023**	**0.009**	25	25	85
Horse - Intense exercise -500 kg[8]	**3.9**	3.1		0.49	**0.15**	**0.033**	**0.095**	**0.069**	**0.018**	26	26	85
Layer	**0.022**	0.016	0.018	0.0050	**0.0016**	**0.00048**	0.00058	**0.0022**		0.088	0.088	75
Swine - Gestating sow-200 kg	0.50	0.45	0.47	0.17	**0.032**	**0.009**	0.022			5.0	5.0	90
Swine - Lactating sow[9] -192 kg	1.2	1.0	1.1	0.38	**0.085**	**0.025**	.053			12	12	90
Swine - Boar-200 kg	0.38	0.34	0.27	0.13	0.028	0.0097	.0176			3.8	3.8	90
	lb / day-animal (d-a)									lb / d-a.	ft^3 / d-a.	% w.b.
Beef - Cow (confinement)[7,10]	**15**	**13**	14	3.0	**0.42**	**0.097**	0.30	**0.20**		-	-	88
Beef - Growing Calf (confinement)	**6.0**	**5.0**	5.2	1.1	**0.29**	**0.055**	0.19	**0.088**		50	0.81	88
Dairy - Lactating cow	**20**	17	18	2.9	**0.99**	**0.17**	**0.23**			150	2.4	87
Dairy - Dry cow	**11**	9.2	9.7	1.4	**0.50**	**0.066**	0.33			83	1.3	87
Dairy - Milk fed calves					0.017							
Dairy - Calf-330lb	3.2				0.14					19	0.30	83
Dairy - Heifer-970 lb	8.2	7.1	7.5	1.2	**0.26**	**0.044**				48	0.78	83
Dairy - Veal-260 lb	0.27				0.033	0.0099	0.044			7.8	0.12	96
Horse - Sedentary-1,100 lb[8]	**8.4**	6.6		1.1	**0.20**	**0.029**	**0.060**	**0.051**	**0.020**	56	0.90	85
Horse - Intense exercise -1,100 lb[8]	**8.6**	6.8		1.1	**0.34**	**0.073**	**0.21**	**0.15**	**0.040**	57	0.92	85
Layer	**0.049**	0.036	0.039	0.011	**0.0035**	**0.0011**	0.0013	0.0048		0.19	0.0031	75
Swine - Gestating sow-440 lb	1.1	0.99	1.0	0.37	**0.071**	**0.020**	0.048			11	0.18	90
Swine - Lactating sow[9] 423 lb	2.5	2.3	2.4	0.84	**0.19**	**0.055**	0.12			25	0.41	90
Swine - Boar-440 lb	0.84	0.75	0.60	0.29	0.061	0.021	0.039			8.4	0.13	90

[1] Prior to any changes due to dilution water addition, drying, volatilization or other physical, chemical or biological processes.

[2] Non-bold table numbers indicate that predictive equations were not available from Sections 4 – 9 for estimating this characteristic. These numbers are average values taken from MWPS-18 Section 1, NRCS Agricultural Waste Management Field Handbook, and the previous version ASAE D384.1 or calculated based upon procedures used in footnote 3.

[3] Total Solids (TS) is estimated for most animal groups by equations in Sections 4 – 9. For beef cattle, volatile solids is also based upon equations. For all other species, volatile solids are calculated from TS and literature values of the ratio of VS to TS. Similarly, BOD and COD values are calculated using VS and the literature values of the ratio of BOD and COD to VS. Literature values are taken from MWPS-18 Section 1, NRCS Agricultural Waste Management Field Handbook, and the previous version ASAE D384.1.

[4] BOD – Biochemical oxygen demand, 5-day, COD – Chemical oxygen demand.

[5] Total manure is calculated from Total Solids and manure moisture content.

[6] As-excreted manure moisture contents range from 75 to 90 percent. At these moisture levels as-excreted manure has a density nearly equal to that of water, and a specific gravity of 1.0 was assumed in calculation of manure volume.

[7] Solids estimates (TS, VS, COD, and BOD) do not include solids in urine.

[8] These values apply to horses 18 months of age or older that are not pregnant or lactating. The representative number applies to 500 kg horses and the range represents horses from 400 to 600 kg. "Sedentary" would apply to horses not receiving any imposed exercise. Dietary inputs are based on minimum nutrient requirements specified in "Nutrient Requirements of Horses" (NRC, 1989). "Intense" represents horses used for competitive activities such as racing. Dietary inputs are based on a survey of race horse feeding practices (Gallagher et al, 1992) and typical feed compositions (forage = 50% alfalfa, 50% timothy; concentrate = 30% oats, 70% mixed performance horse concentrate).

[9] Bold values include contribution of nursing pigs.

[10] Beef cows values are representative of animals during non-lactating period and first six months of gestation.

Table 2. Definition of Variables – As Excreted - Beef – Section 4.

Variable	Description	Units
	Animal performance characteristics input	
BW_F	Live body weight at finish of feeding period (market weight)[2]	kg
BW_I	Live body weight at start of feeding period (purchase weight)[2]	kg
BW_{AVG}	Average live body weight for feeding period [2]	kg
SRW[3]	Standard reference weight for expected final body fat	478 kg for Choice (28% marbling) 462 kg for Select (26.8% marbling)
	Feed program characteristics inputs	
DMI	Dry matter intake	g dry feed / day
DMD	Dry matter digestibility of total ration	% of DMI
OMD	Organic matter digestibility of total ration	% of OMI
ASH	Ash concentration of total ration	% of DMI
C_{cp}	Concentration of crude protein of total ration	g of protein / g of dry feed
C_P	Concentration of phosphorus of total ration	g of phosphorus / g of dry feed
DOF	Days on feed for individual ration	days
x	Ration number	
n	Total number of rations fed	
	Excretion outputs	
N_{E-T}	Total nitrogen excretion per finished animal	g of nitrogen / finished animal
P_{E-T}	Total phosphorus excretion per finished animal	g of phosphorus / finished animal
Ca_{E-T}	Total calcium excretion per finished animal	g of calcium / finished animal
DM_E	Dry matter excretion per animal per day	g of dry matter / day / animal
DM_{E-T}	Total dry matter excretion per finished animal	g of dry matter / finished animal
OM_E	Organic matter (or volatile solids) excretion per animal per day	g of organic matter / day / animal
OM_{E-T}	Total organic matter (or volatile solids) excretion per finished animal	g of organic matter / finished animal

[1] Data specific to individual herd performance or feed analysis should be used when data is available. If situation specific information is not available, a default value from the Assumptions Table for Typical Manure Characteristics at the conclusion of this section may be the next best alternative.

[2] For beef cow/calf pairs (including pregnancy), assume BW_F – BW_I equals weaning weight of calves. For beef cows on maintenance diet, assume the BW_F – BW_I equals 0.

[3] If SRW is unknown, recommend using 478 kg as standard reference weight.

2.2 Sections 4 – 9. Equations for As-Excreted Manure Characteristics Estimates for Individual Species. These sections demonstrate the impact of dietary changes on nutrient excretion. However, this is not intended to be used as a ration-balancing tool, nor is this the appropriate tool for estimating the nutrient needs of the animal. Nutrient needs are best defined in the National Research Council's publication series or by using University recommendations. Both sources of information can provide estimates that reflect biological inefficiencies and digestibility limitations.

2.3 In using Sections 4 – 9 to evaluate the impact of alternative rations, it is important to recognize that these equations accurately estimate excretion only when animals are fed diets that meet or exceed the animal's minimum nutrient requirements. Estimates of excretion based on dietary options that do not meet an animal's minimum needs will not be accurate. Sections 4 – 9 are to be used following ration development by an animal nutrition professional.

2.4 New research data on excretion will be of value for confirming or improving the accuracy of the equations estimating excreting. The authors of this standard are very interested in comparing new research data with these equations. Authors can be contacted through the ASAE Standards staff.

2.5 Section 10. Typical As-Removed Manure Production and Characteristics. Many physical, chemical, and biological processes can alter manure characteristics from its original as-excreted form. The as-removed manure production and characteristics values reported in this table allow for common modifications to excreted manure (Section 3) resulting from water addition or removal, bedding addition, and/or treatment processes. These values represent typical values based on available data sources (see end of Section 10). These estimates may be helpful for individual farm long-term planning prior to any samples being available and for planning estimates addressing regional issues. Whenever possible, site-specific samples or other more localized estimates should be used in lieu of national tabular estimates. **This table should not be used to develop individual year nutrient management plans for defining field specific application rates, unless absolutely**

Table 3a: Estimated manure (urine and feces combined) characteristics as excreted based upon equations in Section 4 and assumptions in Table 3b.

Animal Type and Production Grouping	Total solids	Volatile Solids	Nitrogen	Phosphorus	Calcium	Total Manure[1]
	kg / finished animal					
Finishing cattle	360	290	25	3.3	7.7	3,400
	lb / finished animal					
Finishing cattle	780	640	55	7.3	17	7,400

[1] Total manure is calculated from total solids and assumed moisture of 92%.

Table 3b – Dietary and performance assumptions – Section 4.

Animal Type and Production Grouping	Live Weight (kg)		Average Daily Gain (kg/da)	Days on Feed	Feed Conversion (kg of feed per kg of gain)	Dietary Assumptions						
	In	Out				DMI (% of avg. body weight)	DMD	OMD	Crude Protein (g/day)	P (g/day)	Ca (g/day)	Ash
Finishing cattle	338	554	1.42	153	6.3	2.0%	80%	83%	1200	28	62	4%
Range: Only feed conversion efficiency and dietary nutrient content or digestibility were varied to determine range for N, P, and Ca.					5.8–6.8		70 – 85%	75 – 88%	1100 – 1300	22 – 45	53 – 80	

no site-specific manure analysis data are available. However, where site-specific data are unavailable, this table may provide initial estimates for planning purposes until those site-specific values are available.

3.0 Typical As-Excreted Manure Production and Characteristics

3.1 Two approaches were used for estimating typical characteristics summarized in Table 1.

1) Manure characteristics listed in **BOLD** are estimated for dietary intake and animal performance levels common for livestock and poultry management in 2003 using the equations listed in Sections 4 through 9. Beef, poultry and swine excretion characteristics are based on a calculation of dietary nutrient intake minus animal nutrient retention using dietary and performance measurements typical for the industry at the time these data were published. Nutrient retention estimates followed common industry methodologies used for recommending feeding programs. Dry matter excretion is estimated to be a function of dry matter intake minus dry matter digestibility (see equations in Sections 4 and 9).

   For estimating dairy and equine manure characteristics, existing research data and regression analysis were used to identify relationship between feeding programs, animal performance, and excretion.

   Total nitrogen, total phosphorus, and dry matter excretion were estimated by these methods for all species. Available research data or models allowed additional excretion estimates for some species. All data in Table 1 based upon animal dietary intake and performance measure is illustrated in **BOLD** with supporting assumptions for dietary intake and performance assumptions and references listed in Sections 4 through 9.

2) Where dietary intake and animal performance level based excretion estimates could not be made, a review of current references including the USDA Agricultural Waste Management Field Handbook, previous ASAE D384 standard, and Manure Characteristics (MWPS-18, Section 1). Those values in Table 1 that are not bold are based upon these references.

3.2 Caution

3.2.1 Manure and nutrient production characteristics for meat producing animals are reported on a unit mass excreted per finished animal. Manure excretion by meat producing animals varies with stage of growth. This format was selected to minimize misuse of a daily average values to represent an entire production phase. Sizing of treatment systems based upon instantaneous loading rates should use the equations in Sections 4 through 9 with appropriate feeding program and performance inputs typical of the later stages of growth. Manure excretion rates for other animals are more constant and thus reported on a daily basis.

3.2.2 In addition, facilities for meat producing animals are rarely in full production 365 days per year due to uneven growth rates of animals, time required for facility cleaning after a group, and availability of animals for restocking a facility. Planning based on number of finished animals provides a more realistic planning estimate for annual manure volume and nutrient production.

3.2.3 It should also be noted that Table 1 estimates and predictive equations in Sections 4 through 9 provide an as-excreted estimate of manure production, excluding any additions of waste feed or dilution water, biochemical degradation of solids, or volatilization of nitrogen and carbon. Manure characteristics after storage and/or treatment of manures are better estimated by site-specific manure samples or, when farm specific information is not available, by the typical as-removed values listed in Section 10.

3.3 References

3.3.1 Fulhage, C. D., 2003. Proposed Revision to ASAE D384.1 for Representative Values of “As-Excreted” Manure Production. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 269–276.

4.0 Equations for As-Excreted Manure Characteristics Estimates for Beef

4.1 Fundamental Model

Nutrient Excretion = Feed Nutrient Intake – Nutrient Retention

Dry Matter Excretion = Feed Dry Matter Intake X (1 – Dry Matter Digestibility)*

* Same relationship for organic matter or volatile solids excretion

4.2 See 2.0 Caution

See Table 2, Definitions of Variables – As Excreted – Beef.

4.3 Equations for Estimating Excretions

Equations from the 1996 NRC Nutrient Requirements of Beef Cattle for retained protein and energy equations provide the basis for estimating nitrogen retention. Supplemental information referenced by this publication provides background information on validation of this approach for estimating retained nitrogen.

Retained phosphorus is generally recognized as 3.9 g of retained P per 100 g of retained protein. Retained calcium is generally recognized as 7.1 g per 100 g of retained protein. Therefore, P and Ca retention are calculated as a function of retained protein. Both assumptions originate from the 1996 NRC Nutrient Requirements of Beef Cattle. Additional supporting information is sited by this publication.

4.3.1 *Dry Matter Excretion Equation for Calves and Finishers*[1]

$$DM_E = [DMI * (1 - DMD / 100)] + 20.3 * (0.06 * BW_{AVG}) \quad (1)$$

$$DM_{E-T} = \sum\nolimits^{n}_{x=1} DMI_x * DOF_x * (1 - DMD_x / 100) + \sum\nolimits^{n}_{x=1} DOF_x * 20.3 * (0.06 * BW_{AVG}) \quad (2)$$

---

[1] Estimates dry matter for 1) feces baed upon indigestibility of feed and for 2) urine based upon regression equation from 300 observations of urine excretion by beef cattle finishers ranging in weight from 100 to 620 kg and urine solids content of 6%.

Table 4 – Definition of Variables – As Excreted – Dairy Cattle – Section 5.

Variable	Description	Units
Animal performance characteristics inputs		
Milk	Milk production	kg of milk / animal / day
MF	Milk fat	g / g milk / day
MTP	Milk true protein	g / g milk / day
DIM	Days in milk	days
DP	Dry period length	days
BW	Average live body weight	kg
Feed program characteristics inputs		
DMI	Dry matter intake	kg dry feed / animal / day
DMD	Dry matter digestibility of total ration	% of DMI
OMD	Organic matter digestibility of total ration	% of of OM intake
ASH	Ash concentration of total ration	% of DMI
C_{cp}	Concentration of crude protein of total ration	g crude protein / g dry feed
C_P	Concentration of phosphorus of total ration	g phosphorus / g dry feed
C_K	Concentration of potassium of total ration	g potassium / g dry feed
Excretion outputs		
M_E	Total manure excretion per animal per day	kg / animal / day
N_E	Total nitrogen excretion per animal per day	g / animal / day
P_E	Total phosphorus excretion per animal per day	g / animal / day
K_E	Total potassium excretion per animal per day	g / animal / day
DM_E	Dry matter (solids) excretion per animal per day	kg / animal / day
OM_E	Organic matter (or volatile solids) excretion per animal per day	kg / animal / day
U_E	Urine excretion per animal per day	liters / animal / day

4.3.2 *Organic Matter (or volatile solids) Excretion Equation*

$$\begin{aligned}OM_E = {} & [DMI*(1-ASH / 100)]*(1-OMD / 100) \\ & + 17*(0.06*BW_{AVG})\end{aligned} \tag{3}$$

$$\begin{aligned}OM_{E-T} = {} & \sum^n{}_{x=1} [DMI_x*DOF_x*(1-ASH_x / 100)]*(1-OMD_x \\ & / 100) + \sum^n{}_{x=1} DOF_x*17*(0.06*BW_{AVG})\end{aligned} \tag{4}$$

4.3.3 *Nitrogen Excretion Equation*

$$\begin{aligned}N_{E-T} = {} & \sum^n{}_{x=1}(DMI_x*C_{cp-x}*DOF_x*/6.25)-[41.2*(BW_F \\ & -BW_I)] + [0.243*DOF_{Tt}*[(BW_F \\ & +BW_I)/2]^{0.75}*(SRW/(BW_F*0.96))^{0.75}*[(BW_F \\ & -BW_I)/DOF_T]^{1.097}]\end{aligned} \tag{5}$$

4.3.4 *Phosphorus Excretion Equation*

$$\begin{aligned}P_{E-T} = {} & \sum^n{}_{x=1}(DMI_x*C_{P-x}*DOF_x)-[10.0*(BW_F-BW_I)] \\ & +\{5.92*10^{-2}*DOF_T*[(BW_F \\ & +BW_I)/2]^{0.75}*(SRW/BW_F*0.96)^{0.75}*[(BW_F \\ & -BW_I)/DOF_T]^{1.097}\}\end{aligned} \tag{6}$$

4.3.5 *Calcium Excretion Equation*

$$\begin{aligned}Ca_{E-T} = {} & \sum^n{}_{x=1}(DMI_x*C_{Ca-x}*DOF_x)-[18.33*(BW_F-BW_I)] \\ & +0.445*\{0.243*DOF_T*[(BW_F \\ & +BW_I)/2]^{0.75}*(SRW/(BW_F*0.96))^{0.75}*[(BW_F \\ & -BW_I)/DOF_T]^{1.097}\}\end{aligned} \tag{7}$$

4.4 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 3a and 3b.

4.5 References

4.5.1 Anrique, R. G., M. L. Thonney, and H. J. Ayala. 1990. Dietary energy losses of cattle influenced by body type, size, sex, and intake. Anim. Prod. 50:467–474.

4.5.2 Danner, M. L., D. G. Fox, and J. R. Black. 1980. Effect of feeding system on performance and carcass characteristics of yearling steers, steer calves and heifer calves. J. Anim. Sci. 50:394–404.

4.5.3 Ellenberger, H. G., J. A. Newlander, and C. H. Jones. 1950. Composition of the bodies of dairy cattle. Vt. Agric. Exp. Sta. Bull. 558.

4.5.4 Erickson, G. E., B. Auvermann, R. Eigenberg, L.W. Greene, T. Klopfenstein, R. Koelsch. 2003. Proposed Beef Cattle Manure Excretion and Characteristics Standard for ASAE. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 269–276.

4.5.5 Fortin, A., S. Simpfendorfer, J. T. Reid, H. J. Ayala, R. Anrique, and A. F. Kertz. 1980. Effect of level of energy intake and influence of breed and sex on the chemical composition of cattle. J. Anim. Sci. 51:604–614.

4.5.6 Garrett, W. N. 1980. Energy utilization by growing cattle as determined in 72 comparative slaughter experiments. Energy Metab. Proc. Symp. 26:3–7.

4.5.7 Harpster, H. W. 1978. Energy requirements of cows and the effect of sex, selection, frame size, and energy level on performance of calves of four genetic types. Ph.D. dissertation. Michigan State University, East Lansing, MI.

4.5.8 Lomas, L. W., D. G. Fox, and J. R. Black. 1982. Ammonia treatment of corn silage. I. Feedlot performance of growing and finishing cattle. J. Anim. Sci. 55:909–923.

4.5.9 NRC. 1996 (2000 update). Nutrient Requirements for Beef Cattle. Seventh Revised Edition. National Academy Press. 242 pages.

4.5.10 Tylutki, T. P., D. G. Fox, and R. G. Anrique. 1994. Predicting net energy and protein requirements for growth of implanted and nonimplanted heifers and steers and nonimplanted bulls varying in body size. J. Anim. Sci. 72:1806–1813.

4.5.11 Woody, H. D., D. G. Fox, and J. R. Black. 1983. Effect of diet grain content on performance of growing and finishing cattle. J. Anim. Sci. 57:717–728.

5.0 Equations for As-Excreted Manure Characteristics Estimates for Dairy Cattle

5.1 Fundamental Model

5.1.1 The estimates for manure and nutrient excretion were derived from the combination of multiple data sets from Washington State University, University of California – Davis, The Ohio State University, and Pennsylvania State University. The data sets contain records from Holstein cattle and include a wide variety of animal ages, ranging from calves to multiparous lactating cows.

5.1.2 The data for the calves and heifers were divided according to animal body weight and includes four groups, milk fed calves, weaned calves weighing less than 204 kg, heifers weighing between 274 to 613 kg, and veal calves. Excretion estimates for veal calves were adapted from Sutton et al., 1989. Additional classifications of animals include non-lactating and lactating cows.

5.1.3 Lactating cow excretion estimates were derived from regression equations developed using lactating Holstein cows regardless of body weight or milk production. The data set for lactating cows was evaluated to compare the amount of metabolizable protein (MP) required to the MP supplied to the cow using the 2001 Dairy NRC Model. Only cows fed less than 112% of MP requirements were included in the data set. The average values reported for lactating cows were determined using the regression equation for a cow producing 40 kg of milk. The regression equations were developed using PROC MIXED of SAS, with study included as a random variable (St-Pierre, 2001).

5.2 See 2.0 Caution

See Table 4, Definitions of Variables – As Excreted – Dairy Cattle.

5.3 Equations for Estimating Excretion

In many cases, multiple prediction equations are presented. Note, that while the more simplistic equation requires fewer inputs, the result could be less precise due to the influence of dietary intake of nutrients (more developed equation). Regression equations developed using the data set include both residual errors and errors from the variation between the research trials (inter-study errors). Equations with the lowest residual error should be used whenever the input variables are available.

Assumptions:

1) Urine dry matter, estimated at 4.5%, was used for total solids and moisture calculations. The urine volume was calculated by using a specific gravity of 1.038 g/ml.
2) Milk crude protein was converted to milk true protein using a conversion factor for the Holstein breed of 0.940 (http://www.aipl.arsusda.gov/reference/trueprot.htm).

5.3.1 *Total Manure – Lactating cow regression equations:*[1]

$$M_E = (\text{Milk} \times 0.172) + (\text{DMI} \times 2.207) + (\text{MF} \times 171.830) + (\text{MTP} \times 505.310) - 8.170 \quad (1)$$

Inter-study error = 8.50
Residual error = 7.00

$$M_E = (\text{Milk} \times 0.954) + (\text{BW} \times 0.037) + (\text{DIM} \times 0.017) + (\text{MF} \times 186.720) + (\text{MTP} \times 1141.480) - 33.06 \quad (2)$$

Inter-study error = 5.08
Residual error = 8.33

$$M_E = (\text{Milk} \times 0.647) + 43.212 \quad (3)$$

Inter-study error = 6.94
Residual error = 9.19

5.3.2 *Total Manure – Dry cow regression equation:*[1]

$$M_E = (\text{BW} \times 0.022) + 21.844 \quad (4)$$

Inter-study error = 5.93
Residual error = 5.71

5.3.3 *Total Manure – Heifer regression equations:*[1]

$$M_E = (\text{DMI} \times 3.886) - (\text{BW} \times 0.029) + 5.641 \quad (5)$$

Inter-study error = 5.34
Residual error = 2.61

$$M_E = (\text{BW} \times 0.018) + 17.817 \quad (6)$$

Inter-study error = 4.02
Residual error = 3.55

5.3.4 *Total Solids – Lactating cow regression equations:* [2]

$$DM_E = (\text{DMI} \times 0.350) + 1.017 \quad (7)$$

Inter-study error = 1.13
Residual error = 0.76

$$DM_E = (\text{Milk} \times 0.135) + (\text{BW} \times 0.004) + (\text{DIM} \times 0.004) + (\text{MTP} \times 118.370) - 2.456 \quad (8)$$

Inter-study error = 0.63
Residual error = 1.03

$$DM_E = (\text{Milk} \times 0.096) + 5.073 \quad (9)$$

Inter-study error = 0.78
Residual error = 1.13

---

[1] Total manure equals actual fecal excretion plus actual urine excretion from individual cows collected and weighted on a daily basis.

[2] DM_E = actual fecal dry matter + urine dry matter.

Table 5a – Estimated typical manure (urine and feces combined) characteristics as excreted based upon equations in Section 5 and assumptions in Table 5c.

Animal Type and Production Grouping	Total solids	Nitrogen	P	K	Total Manure[1]	Assumed Moisture
	kg / da-animal					% w.b.
Dairy - Lactating cow	8.9	0.45	0.078	0.10	69	87
Dairy - Dry cow	4.9	0.23			38	87
Dairy - Heifer-440 kg	3.7	0.12	0.020		22	83
	lb / da- animal					% w.b.
Dairy - Lactating cow	20	0.99	0.17	0.23	150	87
Dairy - Dry cow	11	0.50			83	87
Dairy - Heifer-440 kg	8.2	0.26	0.044		48	83
Equation Used for Excretion Estimate						
Dairy - Lactating cow	9	16	22	26	-	
Dairy - Dry cow	11	17	-	-	-	
Dairy - Heifer-440 kg	No Equation	19	24	-	-	

[1] Total manure is calculated from total solids and assumed moisture.

Table 5b – Estimated typical manure (urine and feces combined) characteristics as excreted based upon sources cited in Table 5c.

Animal Type and Production Grouping	Total solids	Nitrogen	P	K	Total Manure[1]	Assumed Moisture
	kg / da-animal					% w.b.
Dairy - Milk fed calves		0.0079				
Dairy - Calf-150 kg	1.4	0.063			8.5	83
Dairy - Veal-118 kg	0.12	0.015	0.0045	0.020	3.5	96.5
	lb / da- animal					% w.b.
Dairy - Milk fed calves		0.017				
Dairy - Calf-150 kg	3.2	0.14			19	83
Dairy - Veal-118 kg	0.27	0.033	0.0099	0.044	7.8	96.5

Table 5c – Dietary and performance assumptions.

Animal Type and Production Grouping	Average Live Weight (kg)	Milk Production (kg)	Dietary Assumptions				Comments or Written Description of Assumptions
			Dry Matter Intake (% of average body weight)	Crude Protein (g/day)	P (g/day)	K (g/day)	
Lactating cow	624	40	3.4	3720	94.7	283	Averages are based on 367 cows
Range	437–810	9.8–86.1	1.1–4.9	1356–5250	40–144	168–443	
Dry cow	755	NA	1.4	1525			Averages are based on 18 cows
Range	413–934		0.7-2.2				
Milk Fed Calves	57.1	NA	1.0	136			Averages based on 16 calves
Calf-150 kg	153	NA	2.21	558			Averages based on 46 calves
Range	86–204		1.56–3.37	275–880			
Dairy Veal	40 to 85	NA	1.89	284	10		
	85 to 150		2.09	491	18		
Heifer-420 kg	437	NA	1.91	923			Averages are based on 60 heifers
Range	274–613		1.43–2.44	500–1688			

5.3.5 *Total Solids – Dry cow regression equation:*[1]

$$DM_E = (DMI \times 0.178) + 2.733 \qquad (10)$$

Inter-study error = 0.74
Residual error = 0.45

$$DM_E = (BW \times 0.004) + 1.863 \qquad (11)$$

Inter-study error = 0.42
Residual error = 0.59

5.3.6 *Urine Volume – Lactating cow regression equations:*

$$U_E = (Milk \times 0.114) + (BW \times 0.016) + (MF \times 97.709) + (MTP \times 353.280) + (C_{CP} \times 62.036) - 16.389 \qquad (12)$$

Inter-study error = 3.87
Residual error = 5.56

$$U_E = (BW \times 0.017) + 11.704 \qquad (13)$$

Inter-study error = 4.67
Residual error = 5.68

(Note: Urine volume could be considerably different, depending on ration mineral content. Insufficient data were available to derive regression equations based on intake of minerals)

5.3.7 *Nitrogen Excretion – Lactating cow regression equations:*[2]

$$N_E = (Milk \times 2.303) + (DIM \times 0.159) + (DMI \times C_{CP} \times 70.138) + (BW \times 0.193) - 56.632 \qquad (14)$$

Inter-study error = 53.07
Residual error = 102.71

$$N_E = (Milk \times 5.959) + (DIM \times 0.237) + (BW \times 0.347) + (MTP \times 4547.910) + (C_{CP} \times 1793.730) - 476.530 \qquad (15)$$

Inter-study error = 42.48
Residual error = 107.01

$$N_E = (Milk \times 4.204) + 283.300 \qquad (16)$$

Inter-study error = 57.8
Residual error = 110.8

5.3.8 *Nitrogen Excretion – Dry cow regression equation:*[2]

$$N_E = (DMI \times 12.747) + (C_{CP} \times 1606.290) - 117.500 \qquad (17)$$

Residual error = 45.51

5.3.9 *Nitrogen Excretion – Heifer regression equations:*[2]

$$N_E = ((DMI \times 1000) \times (C_{CP} / 6.25) \qquad (18)$$

$$N_E = (DMI \times C_{CP} \times 78.390) + 51.350 \qquad (19)$$

Inter-study error = 24.47
Residual error = 10.76

5.3.10 *Phosphorus Excretion – Lactating cow regression equations:*[1]

If diets contain less than 0.004 g P/g dry feed[1]*:*

$$P_E = ((DMI \times 1000) \times \mathbf{C_P}) - (Milk \times 0.9) \qquad (20)$$

If diets contain 0.004 g P/g dry feed or greater:

$$P_E = (Milk \times 0.565) + (MTP \times 816.260) + (DMI \times \mathbf{C_P} \times 421.410) - 9.697 \qquad (21)$$

Inter-study error = 10.81
Residual error = 11.47

$$P_E = (Milk \times 0.773) + 46.015 \qquad (22)$$

Inter-study error = 10.83
Residual error = 14.48

5.3.11 *Phosphorus Excretion – Dry cow regression equation:*[1,2]

$$P_E = (((DMI \times 1000) \times \mathbf{C_P} \times DP) - 264.386)/DP \qquad (23)$$

5.3.12 *Phosphorus Excretion – Heifer regression equation:*[1]

$$P_E = ((DMI \times 1000) \times \mathbf{C_P}) \qquad (24)$$

5.3.13 *Potassium – Lactating cow regression equations:*[3]

$$K_E = (Milk \times 1.822) + (MTP \times 2688.880) + (DMI \times \mathbf{C_K} \times 156.930) - 91.755 \qquad (25)$$

Inter-study error = 16.77
Residual error = 25.27

$$K_E = (Milk \times 1.800) + 31.154 \qquad (26)$$

Inter-study error = 18.89
Residual error = 26.94

5.3.14 *Potassium – Dry cow and heifer regression equation:*[3]

$$K_E = ((DMI \times 1000) \times \mathbf{C_K}) \qquad (27)$$

5.4 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 5a, 5b, and 5c.

5.5 Reference

5.5.1 Nennich, T., J Harrison, D. Meyer, W. Weiss, A. Heinrichs, R. Kincaid, W. Powers, R. Koelsch, P. Wright. 2003. Development of Standards Method to Estimate Manure Production and Nutrient Characteristics from Dairy Cattle. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 263–268.

6.0 Equations for As-Excreted Manure Characteristics Estimates for Horses

6.1 Fundamental Model

Equations for as-excreted manure characteristics are based upon regression analysis from available data sets for N, P, K, Ca and Mg. Other estimates are based on survey data or dietary recommendations (NRC, 1989). The nitrogen data set contained 46-paired values (intake and excretion), with intakes ranging from 130 to 530 mg/kg BW/day (median = 250 g N/kg BW). For P, 128 paired values were used (range = 19–121 mg/kg BW/day; median = 42.8 mg P/kg BW). For K, 28 paired values were used (range 50–404 mg/kg BW/day; median = 193.3 mg K/kg Bw). For Ca, 106 paired values were used (range 9.1 to 247 mg/kg BW/d; median 69.7 mg Ca/kg BW). For Mg, 50 paired values were used (range 18.6 to 131.6 mg Mg/kg BW/d; median 28.2 mg Mg/kg BW).

---

[1] DM_E = actual fecal dry matter + urine dry matter.

[2] Nitrogen excretion = actual fecal N + actual urine N.

[1] Phosphorus excretion = actual fecal P + actual urine P.

[2] The constant was derived from the 2001 Dairy NRC equation (p. 112) for absorbed phosphorus and assumes a 60 day dry period.

[3] Potassium excretion = actual fecal K + actual urine K.

Table 6 – Definition of Variables – As Excreted - Horses – Section 6.

Variable	Description	Units
	Animal performance characteristics input	
BW	Average live body weight	Kg
	Feed program characteristics inputs	
DMI	Dry matter intake	g dry feed / day
DMD	Dry matter digestibility of total ration	%
OMD	Organic matter digestibility of total ration	%
ASH	Ash concentration of total ration	%
C_{cp}	Concentration of crude protein of total ration	g of protein / g of dry feed
C_P	Concentration of phosphorus of total ration	g of phosphorus / g of dry feed
C_K	Concentration of potassium of total ration	g of potassium / g of dry feed
C_{Ca}	Concentration of calcium of total ration	g of calcium / g of dry feed
C_{Mg}	Concentration of magnesium of total ration	g of magnesium / g of dry feed
	Excretion outputs	
N_E	Total nitrogen excretion per animal per day	g / animal / day
P_E	Total phosphorus excretion per animal per day	g / animal / day
K_E	Total potassium excretion per animal per day	g / animal / day
Ca_E	Total calcium excretion per animal per day	g / animal / day
Mg_E	Total magnesium excretion per animal per day	g / animal / day
DM_E	Dry matter excretion (feces + urine) per animal per day	g / animal / day
DM_F	Dry matter excretion (feces only) per animal per day	g / animal / day
F_E	Feces (wet weight) excretion per animal per day	g / animal / day
U_E	Urine excretion per animal per day	g / animal / day

6.2 See 2.0 Caution

See Table 6, Definition of Variables – As Excreted - Horses.

6.3 Equations for Estimating Excretions

6.3.1 *Nitrogen Excretion*

#1: Sedentary horses: $N_E = (55.4*BW*10^{-3})$

$$+(0.586*DMI*C_{cp})/6.25$$

$(R^2 = 0.76)$

#2: Exercised horses: $N_E = (42.9*BW*10^{-3})$

$$+(0.492*DMI*C_{cp})/6.25$$

$(R^2 = 0.94)$

6.3.2 *Phosphorus Excretion*

#3: Sedentary or exercised horses: $P_E = (4.56*BW*10^{-3})$

$$+(0.793*DMI*C_p) \quad (1)$$

$(R^2 = 0.85)$

6.3.3 *Potassium Excretion*

#4: Sedentary or exercised horses: $K_E = (19.4*BW*10^{-3})$

$$+(0.673*DMI*C_k) \quad (2)$$

$(R^2 = 0.62)$

6.3.4 *Calcium Excretion*

#5: Sedentary horses: $Ca_E = (26.6*BW*10^{-3})$

$$+(0.497*DMI*C_{Ca}) \quad (3)$$

$(R^2 = 0.65)$

#6: Exercised horses: $Ca_E = (-5.98*BW*10^{-3})$

$$+(0.804*DMI*C_{Ca}) \quad (4)$$

$(R^2 = 0.73)$

6.3.5 *Magnesium Excretion*

#7: Sedentary or exercised horses: $Mg_E = (9.08*BW*10^{-3})$

$$+(0.545*DMI*C_{Mg}) \quad (5)$$

$(R^2 = 0.68)$

6.3.6 *Dry Matter Excretion (feces)*

#8: Sedentary: $DM_F = [(0.03*BW+1.4)/2.0]*425$ (6)

#9: Exercised: $DM_F = \{[2.0*(0.03*BW+1.4)]/2.85\}*310$ (7)

6.3.7 *Dry Matter Excretion (combined urine and feces):*[1]

#10: Sedentary: $DM_E = 7.2*BW+220$ (8)

#11: Exercised: $DM_E = 7.3*BW+230$ (9)

6.3.8 *Optional estimate of dry matter excretion (feces) for all horses:*

#12: $DM_F = DMI*(1-DMD/100)$ (10)

6.3.9 *Optional estimate of dry matter excretion (combined urine and feces) for all horses:*[2]

#13: $DM_E = [DMI*(1-DMD/100)]+0.64*BW$ (11)

---

[1] Sum of total feces and total urine (equations 12 and 13) and multiplied by an assumed moisture content of 15%.

[2] Alternate approach: Sum of total urine (equation 13) multiplied by assumed urine solids content of 4% and dry matter excretion (equation 10).

6.3.10 *Total Feces*

Sedentary or exercised horses: $F_E = DM_E/0.20$ (12)

6.3.11 *Total Urine*

Sedentary or exercised horses: $U_E = 16*BW$ (13)

6.4 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 7a and 7b.

6.5 References

6.5.1 Lawrence, L., J. Bicudo, E. Wheeler. 2003. Horse Manure Characteristics Literature and Database Review. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 277–284.

6.5.2 Gallagher, K., J. Leech and H. Stowe. 1992. Protein, energy and dry matter consumption by racing thoroughbreds: A field survey. J. Equine Vet Sci. 12:43–48.

6.5.3 NRC. 1989. Nutrient Requirements of Horses. National Academy Press, Washington DC.

Table 7a – Estimated typical manure (urine and feces combined) characteristics as excreted based upon equations in Section 6 and assumptions in Table 7b.

Animal Type and Production Grouping	Total Solids	Nitrogen	P	K	Ca	Mg
	g / da-animal					
Horse-Sedentary-500 kg [1]	3,800	89	13	27	23	9
Horse-Intense exercise-500 kg [1]	3,900	150	33	95	69	18
	lb / da-animal					
Horse-Sedentary-1,100 lb [1]	8.4	0.20	0.029	0.060	0.051	0.020
Horse-Intense exercise-1,100 lb[1]	8.6	0.34	0.073	0.21	0.15	0.040

[1] These values apply to horses 18 months of age or older that are not pregnant or lactating. The representative number applies to 500 kg horses. Under type of horse, classifications are made on amount of regular exercise imposed on horses.

Table 7b – Dietary and performance assumptions.

Animal Type and Production Grouping[1]	Average Live Weight (kg)	Dietary Assumptions						
		Dry Matter Intake (% of average body weight)	Dry Matter Digestibility	Crude Protein (g/day)	P (g/day)	K (g/day)	Ca (g/day	Mg (g/day)
Sedentary- mature[2]	500	1.6	57.5%	656	14	25	20	7.5
Range	400–600	1.6–1.7	57.5%	536–776	11–17	20–30	16–24	6–9
Intense exercise (race horses)[3]	500	2.3	69%	1660	39	127	89	25.3
Range	400–600	2.3–2.4	69%	1328–1992	31–47	101–152	71–106	20–30

[1] These values apply to horses 18 months of age or older that are not pregnant or lactating. The representative number applies to 500 kg horses and the range represents horses from 400 to 600 kg.

[2] "Sedentary" would apply to horses not receiving any imposed exercise. Dietary inputs are based on minimum nutrient requirements specified in "Nutrient Requirements of Horses" (NRC, 1989).

[3] "Intense" represents horses used for competitive activities such as racing. Dietary inputs are based on a survey of race horse feeding practices (Gallagher et al, 1992) and typical feed compositions (forage = 50% alfalfa, 50% timothy; concentrate = 30% oats, 70% mixed performance horse concentrate).

Table 8 – Definition of Input Variables – As Excreted – Poultry (Broilers, Turkeys, and Ducks) – Section 7.

Variable	Description	Units
	Feed program characteristics	
FI_{PH}	Feed intake per phase. Dry matter intake assumed to be 88% of feed intake.	g feed / phase (wet basis)
C_{cp}	Concentration of crude protein of total ration	g of protein / g of feed (wet basis)
C_P	Concentration of phosphorus of total ration	g of phosphorus / g feed (wet basis)
x	Phase number (e.g. number assigned to starter, grower, finisher, withdrawal phase rations)	
n	Total number of phases fed	
DM_{RF}	Retention Factor for dry matter	fraction
N_{RF}	Retention Factor for nitrogen	fraction
P_{RF}	Retention Factor for phosphorus	fraction
K_{RF}	Retention Factor for potassium	fraction
	Excretion outputs	
$N_{E\text{-}PH}$	Nitrogen excretion per phase	g of nitrogen / phase
$N_{E\text{-}T}$	Total nitrogen excretion per finished animal	g of nitrogen / finished animal
$P_{E\text{-}PH}$	Phosphorus excretion per phase	g of phosphorus / per phase
$P_{E\text{-}T}$	Total phosphorus excretion per finished animal	g of phosphorus / finished animal
$K_{E\text{-}PH}$	Potassium excretion per phase	g of potassium / per phase
$K_{E\text{-}T}$	Total potassium excretion per finished animal	g of potassium / finished animal
$DM_{E\text{-}PH}$	Dry matter excretion per phase	g of dry matter / per phase
$DM_{E\text{-}T}$	Total dry matter excretion per finished animal	g of dry matter / finished animal

7.0 Equations for As-Excreted Manure Characteristics Estimates for Poultry (Broilers, Turkeys, and Ducks)

7.1 Fundamental Model

Nutrient Excretion = Feed Nutrient Intake − Nutrient Retention

7.2 See 2.0 Caution

See Table 8, Definition of Input Variables – As excreted – Poultry (Broilers, Turkeys, and Ducks).

7.3 Equations for Estimating Excretions – See Table 9 – Retention Factors for Broilers, Turkeys, and Ducks.

7.3.1 *Dry Matter Excretion Equation*

$$DM_{E-PH} = FI_{PH} * 0.88 * (1 - DM_{RF}) \qquad (1)$$

$$DM_{E-T} = \sum\nolimits^{n}_{x=1} FI_x * 0.88 * (1 - DM_{RF}) \qquad (2)$$

7.3.2 *Nitrogen Excretion Equation*

$$N_{E-PH} = [FI_{PH} * (C_{cp} / 6.25)] * (1 - N_{RF}) \qquad (3)$$

$$N_{E-T} = \sum\nolimits^{n}_{x=1} [FI_x * (C_{cp-x} / 6.25)] * (1 - N_{RF}) \qquad (4)$$

7.3.3 *Phosphorus Excretion Equation*

$$P_{E-PH} = (FI_{PH} * C_p) * (1 - P_{RF}) \qquad (5)$$

$$P_{E-T} = \sum\nolimits^{n}_{x=1} (F_x * C_p) * (1 - P_{RF}) \qquad (6)$$

Note that P_{RF} varies for broilers less than and greater than 32 days of age.

7.3.4 *Potassium Excretion Equation*

$$K_{E-PH} = (FI_{PH} * C_K) * (1 - K_{RF}) \qquad (7)$$

$$K_{E-T} = \sum\nolimits^{n}_{x=1} (F_x * C_K) * (1 - K_{RF}) \qquad (8)$$

7.4 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 10a and 10b.

7.5 References

7.5.1 Applegate,T., L. Potturi, R. Angel. 2003. Model for Estimating Poultry Manure Nutrient Excretion: A Mass Balance Approach. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 296–302.

7.5.2 Angel, R., T. Applegate, S. Bastyr. 2003. Comparison of Two methods for Estimating Broiler Manure Nutrient Excretion: Biological Mass Balance Versus Model Based on Mass Balance Approach. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 303–309.

7.3.5 Table 9 – Retention Factors for Broilers, Turkeys, and Ducks.

Species	Dry Matter (DM_{RF})	Nitrogen (N_{RF})	Phosphorus (P_{RF})	Potassium (K_{RF})
Broiler if < 32 days of age	0.6884	0.602	0.493	0.182
Broiler if >= 32 days of age			0.4102	0.182
Turkey Toms and Hens	0.7479	0.588	0.4798	
Ducks	0.6937	0.657	0.4635	

8.0 Equations for As-Excreted Manure Characteristics Estimates for Poultry (Laying Hens)

8.1 Fundamental Model

Nutrient Excretion = Feed Nutrient Intake − Nutrient Retention

The laying hen model varies from other poultry specie to account for egg production. As such, the model assumes dry matter retention by the hen is equivalent to the sum of energy expenditure for maintenance, heat increment, and egg production as well as solids content within the egg, as is described below.

8.2 See 2.0 Caution

See Table 11, Definition of Input Variables – As Excreted – Poultry (Laying Hens).

8.3 Equations for Estimating Excretions

8.3.1 *Dry Matter Excretion*

$$DM_E = [FI * 0.88] - \{(FI * 0.88 * 0.85) * [1 - (\{KCAL_I - [KCAL_m + KCAL_h + (KCAL_e * Egg_{prod})]\} / KCAL_i)] + (0.3319 * Egg_{wt} * Egg_{prod})\}$$

OR (1)

$$DM_E = [FI * 0.88] - \{(FI * 0.88 * 0.85) * [1 - (\{KCAL_I - [140 + (53 * Egg_{prod})]\} / KCAL_i)] + (0.3319 * Egg_{wt} * Egg_{prod})\}$$

8.3.2 *Nitrogen Excretion*

$$N_E = (FI * C_{cp} / 6.25) - (0.0182 * Egg_{wt} * Egg_{prod}) \quad (2)$$

Table 10a – Estimated typical manure (urine and feces combined) characteristics as excreted based upon equations in Section 7 and assumptions in Table 10b.

Animal Type and Production Grouping	Total solids	Nitrogen	Phosphorus	Potassium	Total Manure[1]
	kg / finished animal				
Poultry - Broiler	1.3	0.053	0.016	0.031	4.9
Poultry - Turkey (male)	9.2	0.55	0.16		36
Poultry - Turkey (females)	4.4	0.26	0.074		17
Poultry – Duck	1.7	0.062	0.022		6.5
	lb / finished animal				
Poultry - Broiler	2.8	0.12	0.035	0.068	11
Poultry - Turkey (male)	20	1.2	0.36		78
Poultry - Turkey (females)	9.8	0.57	0.16		38
Poultry - Duck	3.7	0.14	0.048		14

[1] Total manure is calculated from total solids and assumed moisture of 74%.

Table 10b – Dietary and performance assumptions.

Animal Type and Production Grouping	Live Weight (kg)		Days on Feed	Feed Conversion (kg of feed per kg of gain)	Dietary Assumptions			Comments, Assumption or References
	In	Out			Dry Matter Intake (kg per phase)	Crude Protein (kg per phase)	P (kg per phase)	
Broiler	n/a	2.36	47.7	1.95	4.05 kg to 47.7 d	0.835 kg to 47.7 d	0.0288 kg to 47.7 d	Represents 95.8% of broilers marketed July 2002 (662 million birds or 1.53 billion kg live weight). Agristats, 2002 Four diet feeding program is assumed.
Turkey (male)	n/a	15.45	133	2.70	36.7 kg to 133 d	8.37 kg to 133 d	0.309 kg to 133 d	Represents 45.5 million turkey toms (Ferket 2001). Six diet feeding program is assumed.
Turkey (females)	n/a	6.82	105	2.34	17.6 kg to 105 d	3.94 kg to 105 d	0.143 kg to 105 d	Represents 59.5 million turkey hens (Ferket 2001). Six diet feeding program is assumed.
Duck	n/a	3.182	39	1.97	5.51 kg to 39 d	1.12 kg to 39 d	0.0402 kg to 39 d	Represents 13 million ducks (Applegate et al., 2003) Assumes two diet feeding program.

Assumptions: Feed is 88% dry matter.

Table 11 – Definition of Input Variables – As Excreted – Poultry (Laying Hens) – Section 8.

Variable	Description	Units
FI	Feed intake per day (wet weight). Dry matter intake assumed to be 88% of feed intake for poultry rations.	Grams / day
$KCAL_i$	Kcal intake Default: 270 kcal – Light layer strains Default: 292 kcal – Heavy layer strains	Kcal / day
$KCAL_m$	Kcal required for maintenance of body weight Default: 100 kcal	Kcal / day
$KCAL_h$	Kcal required for heat increment in thermo-neutral environment Default: 40 kcal	Kcal / day
$KCAL_e$	Kcal required for egg production of one egg Default: 53 kcal	Kcal / egg
Egg_{wt}	Egg weight Default: 60 g – Light layer strains Default: 63 g – Heavy layer strains	Grams
Egg_{prod}	Fraction of eggs that are produced each day Default: 0.80	Eggs / hen / day
C_{cp}	Concentration of crude protein of total ration	g of protein / g of feed (wet basis)
C_P	Concentration of phosphorus of total ration	g of phosphorus / g feed (wet basis)
C_{Ca}	Concentration of calcium of total ration	g of calcium / g feed (wet basis)
	Excretion outputs	
DM_E	Dry matter excretion per hen per day	g of dry matter / hen - day
N_E	Total nitrogen excretion per hen per day	g of nitrogen / hen - day
P_E	Total phosphorus excretion per hen per day	g of phosphorus / hen - day
Ca_E	Total calcium excretion per hen per day	g of phosphorus / hen - day

8.3.3 *Phosphorus Excretion*

$$P_E = (FI * C_P) - (0.0024 * Egg_{wt} * Egg_{prod}) \quad (3)$$

8.3.4 *Calcium Excretion*

$$Ca_E = (FI * C_{Ca}) - (0.00383 * Egg_{wt} * Egg_{prod}) \quad (4)$$

8.4 Assumptions: Diet contains 15% ash content and corrects diet energy retention to an ash-free, dry matter basis. Egg contains 33.19% solids, 1.82% N, 0.24% P, & 3.83% Ca. DM retention by hen is equivalent to energy expenditure for maintenance (100 kcal/hen, NRC, 1994; Lasiewski and Dawson, 1967), heat increment (40 kcal; NRC, 1994; MacLeod and Jewitt, 1988), and egg production (53 kcal/egg; NRC, 1994).

8.5 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 12a and 12b.

8.6 References

8.6.1 Applegate, T., L. Potturi, R. Angel. 2003. Model for Estimating Poultry Manure Nutrient Excretion: A Mass Balance Approach.

Table 12a – Estimated typical manure (urine and feces combined) characteristics as excreted based upon equations in Section 8 and assumptions in Table 12b.

Animal Type and Production Grouping	Total solids	Nitrogen	Phosphorus	Calcium	Total Manure[1]
	kg / da–animal				
Layer	0.022	0.0016	0.00048	0.0022	0.088
	lb / da–animal				
Layer	0.049	0.0035	0.0011	0.0048	0.19

[1] Total manure is calculated from total solids and assumed moisture of 75%.

Table 12b – Dietary and performance assumptions.

Animal Type and Production Grouping	Average Live Weight (kg)	Feed Conversion (kg of feed per kg of product)	Dietary Assumptions			Comments or Written Description of Assumptions Reference [1]
			Dry Matter Intake (g per phase)	Crude Protein (g per phase)	P (g per phase)	
Layer	1.3–1.45 at start	1.994	36.64 kg from 20–80 wk	6500.4 g from 20–80 wk	249.0 g from 20–80 wk	20–80 wk production cycle. Feed is 88% dry matter 64% and 36% of industry is light (1.28 kg) and heavy (1.45) weight strains, respectively. A weekly change in diet formulation, feed consumption, and egg production was assumed from average performance.

Table 13 – Definition of Output Variables (used for all swine groups) – Section 9.

Variable	Description	Units
	Nutrient Intake	
N_I	Daily nitrogen intake	g / day
N_{I-T}	Nitrogen intake per finished animal or period (e.g. lactation)	g / finished animal or g / period
P_I	Daily phosphorus intake	g / day
P_{I-T}	Phosphorus intake per finished animal or period (e.g. lactation)	g / finished animal or g / period
	Nutrient Retention	
N_R	Daily nitrogen retained	g / day
N_{R-T}	Nitrogen retained per finished animal or period (e.g. lactation)	g / finished animal or g / period
WBN_F	Whole body nitrogen content at final body weight	g
WBN_I	Whole body nitrogen content at initial body weight	g
P_R	Daily phosphorus retained	g / day
P_{R-T}	Phosphorus retained per finished animal or period (e.g. lactation)	g / finished animal or g / period
	Nutrient Excretion	
N_E	Daily nitrogen excretion	g / day
N_{E-T}	Total nitrogen excretion per finished animal or period (e.g. lactation)	g / finished animal or g / period
P_E	Daily phosphorus excretion	g / day
P_{E-T}	Total phosphorus excretion per finished animal or period (e.g. lactation)	g / finished animal or g / period
DM_E	Daily dry matter excretion	g / day
DM_{E-T}	Total dry matter excretion per finished animal or period (e.g. lactation)	g / finished animal or g / period

Table 14 – Input Variables—Grow-finish Pigs (20 to 120 kg) – Section 9.3.

Variable	Description	Units
	Animal performance characteristics	
BW_I	Initial body weight	kg
BW_F	Final body weight (market weight)	kg
BW_{AVG}	Average of initial and final body weight	kg
DOF_G	Days on feed to finish animal (grow-finish phase)	days
DP_F	Average dressing percent (yield) at final weight. Typically from packer kill sheet.	%
$FFLP_F$	Average fat-free lean percentage at final weight. Typically from packer kill sheet.	%
	Feed program characteristics	
$ADFI_G$	Average daily feed intake over finishing period (grow – finish phase). User provided or see NRC (1998)	g / d
FI_G	Feed Intake per finished animal (grow – finish phase)	g/finished animal
C_{CP}	Concentration of crude protein in total (wet) ration	%
C_P	Concentration of phosphorus in total (wet) ration	%
C_{DM}	Dry matter concentration of diet	%
DMD	Dry matter digestibility of total ration	%

Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 296–302.

9.0 Equations for As-Excreted Manure Characteristics Estimates for Swine

9.1 Fundamental Model

Nutrient Excretion = Nutrient Feed Intake − Nutrient Retention

9.2 See 2.0 Caution

See Table 13, Definition of Output Variables (using all swine groups).

9.3 Equations for Estimating Excretions– See Table 14, Input Variables—Grow-finish Pigs (20 to 120kg).

9.3.1 *Nutrient and Solids Excretion—Grow-finish Pigs (20 to 120 kg)*

$$N_{E-T} = N_{I-T} - N_{R-T} \quad (1)$$

$$P_{E-T} = P_{I-T} - P_{R-T} \quad (2)$$

$$DM_{E-T} = [C_{DM} * FI_G * (100-DMD) / 10{,}000] + [0.025 * DOF_G * (20 * BW_{AVG} + 2{,}100)] \quad (3)$$

9.3.2 *Nutrient Intake – Grow-finish Pigs (20 to 120 kg)*

$$N_{I-T} = ADFI_G * C_{CP} * DOF_G / 625 \quad \text{OR} \quad FI_G * C_{CP} / 625 \quad (4)$$

$$P_{I-T} = ADFI_G * C_P * DOF_G / 100 \quad \text{OR} \quad FI_G * C_P / 100 \quad (5)$$

Table 15 – Definition of Input Variables - Weanling Pigs (5 to 20 kg) – Section 9.4.

Variable	Description	Units
	Animal performance characteristics	
$BW_{I\text{-}N}$	Initial body weight in nursery phase	kg
$BW_{F\text{-}N}$	Final body weight in nursery phase	kg
DOF_N	Days on feed to finish animal (nursery phase)	days
DP_{120}	Average dressing percent (yield) at 120 kg. Typically from packer kill sheet.	%
$FFLG_G$	Average fat-free lean gain from 20 to 120 kg. Recommended values: 350 g/day High lean growth capacity pigs 325 g/day High-moderate lean growth capacity pigs 300 g/day Moderate lean growth capacity pigs Source: National Research Council. 1998. Nutrient Requirements of Swine. National Academy Press. Washington, D. C. 189 pages.	g / d
	Feed program characteristics	
$ADFI_N$	Average daily feed intake over finishing period (nursery phase). User provided or see NRC (1998)	g / d
FI_N	Feed Intake per finished animal (nursery phase)	g / finished animal
C_{CP}	Concentration of crude protein in total (wet) ration	%
C_P	Concentration of phosphorus in total (wet) ration	%
C_{DM}	Dry matter concentration of diet	%
DMD	Dry matter digestibility of total ration	%

Table 16 – Input Variables - Gestating Sows – Section 9.5.

Variable	Description	Units
	Animal performance characteristics	
GLTG	Gestation Lean Tissue Gain Recommended value: 19.205 kg	kg
GL	Gestation period length (assumed to be 115 days)	days
SW_{Breed}	Sow body weight at breeding	kg
SW_{PF}	Sow body weight post farrowing	kg
LW_{Birth}	Litter weight at birth	kg
LITTER	Number of pigs in litter	Number of pigs
	Feed program characteristics	
$ADFI_S$	Average daily feed intake during gestation	g / d
C_{CP}	Concentration of crude protein	%
C_P	Concentration of phosphorus	%
C_{DM}	Dry matter concentration of diet	%
DMD	Dry matter digestibility of total ration	%

9.3.3 *Nutrient Retention – Grow-finish Pigs (20 to 120 kg)*[1]

$$N_{R-T} = [(BW_F * DP_F * FFLP_F) / 159.4] - \{BW_I * [DP_F - 0.05 * (BW_F - BW_I)] * [FFLP_F + 0.07 * (BW_F - BW_I)]\} / 159.4 \quad (6)$$

$$P_{R-T} = (0.2256 * N_{RT}) - [8.0 * 10^{-6} * N_{RT} * (WBN_I + WBN_F)] \quad (7)$$

$$WBN_F = (BW_F * DP_F * FFLP_F) / 159.4 \quad (8)$$

$$WBN_I = BW_I * \{DP_F - [0.05 * (BW_F - BW_I)]\} * \{FFLP_F + [0.07 * (BW_F - BW_I)]\} / 159.4 \quad (9)$$

Daily excretion of solids, nitrogen and phosphorus can be estimated by dividing total excretion estimated above by days on feed for the grow-finish phase (DOF_G).

9.4 Equations for Estimating Excretions – See Table 15, Definition of Input Variables – Weanling Pigs (5 to 20kg).

9.4.1 *Nutrient and Solids Excretion—Weanling Pigs (5 to 20 kg)*[1]

$$N_{E-T} = N_{I-T} - N_{R-T} \quad (1)$$

$$P_{E-T} = P_{I-T} - P_{R-T} \quad (2)$$

$$DM_{E-T} = C_{DM} * ADFI_N * DOF_N * (100\text{–}DMD) / 10{,}000\ ^1 \quad (3)$$

9.4.2 *Nutrient Intake – Weanling Pigs (5 to 20 kg)*

$$N_{I-T} = ADFI_N * C_{CP} * DOF_N / 625 \quad \text{OR} \quad FI_N * C_{CP} / 625 \quad (4)$$

$$P_{I-T} = ADFI_N * C_P * DOF_N / 100 \quad \text{OR} \quad FI_N * C_P / 100 \quad (5)$$

9.4.3 *Nutrient Retention – Weanling Pigs (5 to 20 kg)*[2]

$$N_{R-T} = DOF_N * FFLG_G * \{1 + [0.137 * (BW_{F-N} + BW_{I-N})]\} / 125.8 \quad (6)$$

$$P_{R-T} = 4.7494 * (BW_{F-N} - BW_{I-N}) \quad (7)$$

---

[1] P retention based on relation to N (Jongbloed, 1987).

[1] Dry matter excretion in feces only.

[2] P retention based on relation to N (Jongbloed, 1987).

Table 17 – Input Variables – Lactating Sows – Section 9.6.

Variable	Description	Units
Animal performance characteristics		
LLTG	Lactation Lean Tissue Gain Recommended value: -4.20 kg	kg
LL	Lactation length (or time to weaning)	days
SW_{WEAN}	Sow body weight at litter weaning	kg
SW_{PF}	Sow body weight post farrowing	kg
LW_{WEAN}	Litter weight at weaning	kg
LW_{BIRTH}	Litter weight at birth	kg
Feed program characteristics		
$ADFI_{LACT}$	Average daily feed intake during lactation	g / d
C_{CP}	Concentration of crude protein	%
C_P	Concentration of phosphorus	%
C_{DM}	Dry matter concentration of diet	%
DMD	Dry matter digestibility of total ration	%

Table 18a – Estimated typical manure (urine and feces combined) characteristics as excreted based upon equations in Section 9 and assumptions in Table 18b.

Animal Type and Production Grouping	Total solids	Nitrogen	P	Total solids[1]	Nitrogen	P
	kg / finished animal			lb / finished animal		
Swine - Nursery pig (12.5 kg)		0.41	0.068		0.91	0.15
Swine - Grow-finish (70 kg)	56	4.7	0.76	120	10	1.7
	kg / day–animal			lb / day–animal		
Swine - Gestating sow-200 kg		0.032	0.009		0.071	0.020
Swine - Lactating sow-192 kg		0.085	0.025		0.19	0.055

[1] Total solids include urine and feces.

Table 18b – Dietary and performance assumptions of growing swine.[1,2]

Animal Type and Production Grouping	Live Weight (kg)		Average Daily Gain (kg/da)	Days on Feed	Feed Conversion (kg of feed per kg of gain)	Dietary Assumptions			
	In	Out				Dry Matter Intake (% of avg. body weight)	Dry Matter Digestibility	Crude Protein (g/day)	P (g/day)
Nursery pig (12.5 kg)[1,2]	5	20	0.412	36	1.50	5.0	80%	137	3.88
Grow-finish (70 kg)[1,2]	20	120	0.84	120	2.80	3.4	82%	371	10.3

[1] Feed is 88% dry matter. Corn-soybean meal-animal protein (weanling pig) or corn-soybean meal (grow-finish) diet meets the lysine requirement.

[2] N and P intake is based on NRC (1998). N and P retention are based on NRC (1998). P retention is based on Mahan and Newton (1995).

Table 18c – Dietary and performance assumptions of sows.[1,2]

Animal Type and Production Grouping	Average Live Weight (kg)	Production	Dietary Assumptions				Comments or Written Description of Assumptions Reference[1]
			Dry Matter Intake (% of average body weight)	Dry Matter Digestibility	Crude Protein (g/day)	P (g/day)	
Gestating sow-200 kg (start 175 kg, end 225 kg)[1,2] 115 day gestation period	200	12 pigs / litter	1.00	82%	259	12.4	Wt gain = 50 kg with 27 kg wt gain with litter & 23.0 kg wt gain for dam Gestation lean tissue gain = 17.6 kg
Lactating sow-192 kg (Start 198 kg, end 185 kg)[1,2] 20 day lactation period	192	10 pigs nursing	2.60	82%	967	34	Wt change = −13 kg Lactation lean tissue change = −5.3 kg

[1] Assumes corn-soy diet that is 88 % dry matter and meets the lysine requirement.

[2] N and P intake is based on NRC (1998). N retention is based on NRC (1998). P retention is based on Mahan and Newton (1995).

Table 19 – As-Removed Manure Production and Characteristics. The numbers in parenthesis are coefficients of variation.

	Moisture (% wb)	TS (% wb)	VS (% TS)	Ash (% TS)	Heat (BTU/lb wb)	TKN (% wb)	NH3-N (% wb)	P (% wb)	K (% wb)	Ca (% wb)	Na (ppm wb)	Mg (ppm wb)	Fe (ppm wb)	S (ppm wb)	Cl (ppm wb)	Zn (ppm wb)	Mn (ppm wb)	Cu (ppm wb)	Mass (Kg/hd/d)
Beef																			
Earthen Lot	33.1 (28)	67.2 (14)	30.2 (30)	69.9 (24)	1136 (15)	1.18 (33)	0.10 (102)	0.50 (36)	1.25 (25)	1.21 (46)	3012 (67)	3650 (27)	1305 (55)	2841 (37)	7396 (52)	85 (63)	393 (109)	14 (70)	7.5 (0.58)
Poultry																			
Leghorn pullets	65.20 (14)	40				2.13 (31)	0.85 (22)	1.00 (25)	1.10 (29)	1.49 (33)		2700 (26)							No data
Leghorn hen	59.27 (14)	40				1.85 (30)	0.88 (39)	1.21 (34)	1.31 (28)	6.40 (41)		4400 (32)							0.03
Broiler litter	31.00 (24)	70	70			3.73 (14)	0.75	0.60 (22)	1.37 (13)	1.82 (17)									0.02
Turkey litter	30.00					2.18		0.33	1.23	5.00									0.11
Dairy																			
Scraped earthen lots	54 (28)	46 (33)		43		0.70 (106)		0.25 (82)	0.67 (71)	0.45 (78)	311 (45)	100 (64)	4.6 (66)		86.0	1.2 (42)	1.4	0.2 (21)	35
Scraped concrete lots	72	25				0.53		0.13	0.40	0.31	32	9	1.3			0.4	0.7	0.1	40
Lagoon effluent	98	2	52			0.073	0.08	0.016	0.11	0.04	7	3	2.5		1.7	0.9	1.4	2	106
Slurry (liquid)	92 (1)	8 (16)	66			0.30	0.14	0.13	0.40	0.40	905	1535	735	625		25	40	75	67
Equine																			
Solid manure	43.4 (16.1)	64.9 (19.7)	26.3 (10.3)			0.76 (0.36)		0.24 (0.11)	0.99 (0.58)	1.13 (0.72)		0.3 (0.18)	3614 (4722)			51.7 (33.66)	135 (60)	12.70 (6.02)	32.2 (residential) 46 (commercial)
Swine																			
Finisher-Slurry, wet-dry feeders	91.00	9.00				0.70	0.50	0.21	0.24	0.25	380			400		85.0		50	3–4
Slurry storage-Dry feeders	93.90	6.10 (86)				0.47 (43)	0.34 (43)	0.18 (83)	0.24 (36)	0.25 (98)	380 (24)			180 (55)		68 (53)		30 (56)	4.5
Flush building	98.00	2.00				0.20	0.14	0.07	0.17	0.04	300	290		155		33.6	14.4	31.2	16
Agitated solids and water	97.80	2.20				0.10	0.05	0.06	0.06	0.08	215	300		180		44.4	15.6	19.2	
Lagoon surface water	99.6	0.40				0.06	0.04	0.02	0.07	0.01	215	55		37		3.6	1.2	2.4	
Lagoon sludge	90.0	10.0				0.26	0.07	0.25	0.07	0.04	191	132		79		22	80	90	

Table 20 – References

The numbers in the table are rounded averages gathered from across the U.S. They are best estimate interpretations based on the research data collected.

BEEF earthen lots	**Concrete lots**		
Nebraska unpub (12 lots, 96 hd ea) NC State (n~30) Texas AM University (n~4) Oklahoma State University (n = 72) Ward lab (n = 1026) $\sum$ = **1144**	Iowa unpublished data (N ~ 6) NC State (n ~ 27) NOTE: not enough data to publish estimates for conc. lots		
DAIRY ESTIMATES			
Scraped Earthen lots Jones (Texas, n ~ 17) TAMU (n ~ 5) Dairyland (n ~ 77) Agsource (n ~ 367) $\sum$ = 476	**Scraped Concrete lots** N.C. State data (n ~ 187) TAMU (n ~ 3) ISU (n ~ 18) KSU (n ~ 9) $\sum$ = 190	**Lagoon effluent** N.C. State data (~160) Meyer (n~ 518) NY (n~57) TAMU (n~18) $\sum$ = 753	**Liquid Slurry** N.C. State data (n ~ 400) Minn (n ~ 21) NY (n ~ 39) Kansas (n ~ 18, Stram et al.) Wisc (n ~ 746) Dairyland (n ~ 216) Agsource (n ~ 514) NRAES-31, 1989, Collins et al.) $\sum$ = 1954
SWINE			
Deep Pit Slurry ISU Jaranilla (n = 24) ISU NIR data (n = 268) (1999 & 2000 data) $\sum$ = 292	**Flush water** SE US data (Chastain)	**Lagoon Surface Water** SE US data (Chastain) Mo. Data ISU NIR data (n = 189) $\sum$ = 189+	**Agitated liquid & solids** SE US data (Chastain)
POULTRY			
Pullets Patterson	**Layer hens** Patterson ISU (Lorimor & Xin, n = 48)	**Broiler litter** ISU (Mo & Okla samples, n = 95)	**Turkey litter**

Daily excretion of solids, nitrogen and phosphorus can be estimated by dividing total excretion estimated above by days on feed for nursery phase (DOF_N).

9.5 Equations for Estimating Excretions – See Table 16, Input Variables – Gestating Sows.

9.5.1 *Nutrient and Solids Excretion – Gestating Sows*[1]

$$N_{E-T} = N_{I-T} - N_{R-T} \tag{1}$$

$$P_{E-T} = P_{I-T} - P_{R-T} \tag{2}$$

$$DM_{E-T} = C_{DM} * ADFI_S * GL * (100 - DMD) / 10{,}000$$
$$= C_{DM} * ADFI_S * 0.0115 * (100 - DMD)^1 \tag{3}$$

9.5.2 *Nutrient Intake – Gestating Sows*[1]

$$N_{I-T} = ADFI_S * C_{CP} * GL / 625 = ADFI_S * C_{CP} * 0.184 \tag{4}$$

$$P_{I-T} = ADFI_S * C_P * GL / 100 = ADFI_S * C_P * 1.15 \tag{5}$$

9.5.3 *Nitrogen Retention – Gestating Sows*[2]

$$N_{R-T} = (GLTG \times 36.8) + (LITTER \times 39.1) \tag{6}$$

$$P_{R-T} = 93.039 + \{3.9717 \times [(SW_{PF} - SW_B) - (2.277 * LITTER)]\} + (LW_{Birth} \times 5.7) + \{[(2.277 \times LITTER) - LW_{Birth}] \times 0.80\} \tag{7}$$

Note: N_{R-T} accounts for nitrogen retention in maternal weight gain and the developing litter. P_{R-T} considers phosphorus retention in maternal weight gain, developing litter and placenta tissue.

Daily excretion of solids, nitrogen and phosphorus can be estimated by dividing total excretion estimated above by gestation length (GL) in days.

9.6 Equations for Estimating Excretions – See Table 17, Input Variables – Lactating Sows.

9.6.1 *Nutrient and Solids Excretion – Lactating Sows*

$$N_{E-T} = N_{I-T} - N_{R-T} \tag{1}$$

$$P_{E-T} = P_{I-T} - P_{R-T} \tag{2}$$

$$DM_{E-T} = C_{DM} * ADFI_L * LL * (100-DMD) / 10{,}000^1 \tag{3}$$

9.6.2 *Nutrient Intake – Lactating Sows*

$$N_{I-T} = ADFI_{LACT} * C_{CP} * LL/625 \tag{4}$$

---

[1] Dry matter excretion in feces only.

[2] Assumes gestation period length of 115 days.

[1] Dry matter excretion in feces only.

$$P_{I-T} = ADFI_{LACT} * C_P * LL/100 \quad (5)$$

9.6.3 *Nutrient Retention – Lactating Sows*

$$N_{R-T} = [36.8 \times LLTG] + (LW_{WEAN} \times 32) - (LW_{BIRTH} \times 36.8) \quad (6)$$

$$P_{R-T} = [(SW_{WEAN} \times 4.84) - (SW_{PF} \times 5.28)] + [(LW_{WEAN} \times 6.4) - (LW_{BIRTH} \times 5.7)] \quad (7)$$

Daily excretion of solids, nitrogen and phosphorus can be estimated by dividing total excretion estimated above by lactation length (LL) in days.

9.7 Manure Characteristics Based Upon Typical Performance and Diets – See Tables 18a, 18b, and 18c.

9.8 References

9.8.1 Carter, S., G. Cromwell, P. Westerman, J. Park, and L. Pettey. 2003. Prediction of Nitrogen, Phosphorus, and Dry Matter Excretion by Swine Based on Diet Chemical Composition, Feed Intake, and Nutrient Retention. Proceedings of the International Symposium for Animal, Agricultural, and Food Processing Wastes IX. ASAE. St. Joseph, MI. 285–295.

10.0 As-Removed Manure Production and Characteristics

10.1 Many physical, chemical, and biological processes can alter manure characteristics from its original as-excreted form. The as-removed manure production and characteristics values reported in this table allow for common modifications to excreted manure (Section 3) resulting from water addition or removal, bedding addition, and/or treatment processes. These values represent typical values based on available data sources (see end of Section 10). The variances on the data presented in Section 10, As-Removed Manure Production and Characteristics, are significantly high, and strongly correlated to the geographic location and the type of manure management system in use. These estimates may be helpful for individual farm long-term planning prior to any samples being available and for planning estimates addressing regional issues. Whenever possible, site-specific samples or other more localized estimates should be used in lieu of national tabular estimates. **This table should not be used to develop individual year nutrient management plans for defining field specific application rates, unless absolutely no site-specific manure analysis data are available.** Where site-specific data are unavailable, this table may provide initial estimates for planning purposes until site-specific values are available.

See Tables 19 and 20.

10.2 References (continued)

10.2.1 Barker, J.C., J.P. Zublena, C.R. Campbell. 1994. Unpublished compilation of manure samples of all species and facilities. North Carolina State Univ. Raleigh, N.C.

10.2.2 Stram, T.D., J.P. Harner, D.V. Key, and J.P. Murphy. 2000. Nutrients available from dairy lagoons and sand-laden manure. Presented at Mid Central Meeting of ASAE. ASAE paper MC00-120

10.2.3 Collins, E.R., T.A. Dillaha, and H.W. Roller. 1989. Dairy manure management. NRAES-31

10.2.4 Lorimor, J.C., and H. Xin. 1999. Manure production and nutrient concentrations from high-rise layer houses. ASAE Trans. 15(4): 337-340

10.2.5 Patterson, P.H. and E.S. Lorenz. 1996. Manure nutrient production from commercial white leghorn hens. Applied Poultry Science Research report.

10.2.6 Lorimor, J.C., W. Powers, A. Sutton. 2000. Manure characteristics. MWPS18-Section 1. Midwest Plan Service. Ames, IA.

10.2.7 Lorimor, J.C., 1999. Managing manure nutrients for crop production. ISU Extension publication Pm-1811. Ames, IA.

10.2.8 Chastain, J.P. 2002. Nutrient content of swine manure as removed. Unpublished data compiled by the author.

10.2.9 Erickson, G.A., T. Klopfensteein, D. Walters, and G. Lesoing. 1998. Nutrient balance of nitrogen, organic matter, phosphorus and sulfur in the feedlot. Nebraska Beef Report, Univ. of Neb. Lincoln, NB.

10.2.10 Ward Lab. 2003 data accumulated from commercial lab. (603 samples)

10.2.11 Lorimor, J.C. 2003. Unpublished data compiled by author on earthen beef feedlots in IA.

10.2.12 Jaranilla-Sanchez, P.A., J.C. Lorimor, and J. Boeding. 2003. Manure Accumulation in a Deep Pit Finishing Building. Presented at Mid Central Meeting of ASAE. ASAE paper MC03-403.

10.2.13 Bicudo, J. 2003. Compilation of unpublished data. Numbers were based on analyses of stall waste made in KY, TX, CO, Alberta (Canada), OK, and WA.

10.2.14 Ye, W. 2003. Application of near-infrared spectroscopy for determination of nutrient contents in manure. Ph.D. dissertation, Iowa State University.

ATTACHMENT #6

Dry Nonheated Anaerobic Biogas Fermentation Using Aged Beef Cattle Manure

D. B. Parker, J. S. Posey, D. L. Williams, N. A. Cole, B. W. Auvermann, W. J. Rogers

ABSTRACT

Biogas production at beef cattle feedlots is hard to justify because of the large amounts of dilution water required and the high cost to design and operate conventional water-based digestion systems. Laboratory and field experiments were conducted to determine the feasibility of producing biogas using "dry" aged beef cattle manure scraped from open-lot feedyards. Biogas production rates were measured at 21°C in the laboratory at four total solids contents using a water displacement technique. Biogas yields were 0.180, 0.210, 0.190 and 0.005 L per gram volatile solids (VS) at solids contents of 20, 30, 40 and 50 percent, respectively. Biogas was produced steadily for 300 days before declining and eventually ceasing after 450 days. The biogas contained 52 to 60 percent methane. A field demonstration project was conducted to produce biogas using geomembrane-lined digesters. Two 90 m^3 digesters excavated in native soil to a depth of 1.8 m were lined on top and bottom with ethylene propylene diene monomer (EPDM) geomembranes. Digester 1 was loaded with manure (solids content 40 percent) in February, 1999. Biogas was produced during the first summer for 12 weeks beginning August 1, 1999, and during the second summer for 13 weeks beginning July 14, 2000. Digester 1 produced 1,510 m^3 of biogas the first summer and 920 m^3 the second summer, with a typical methane concentration of 52 percent. Total biogas yield over the two summers was 0.16 L/g VS in digester 1. Digester 2 was loaded with manure (solids content 50 percent) in January, 2000, and produced less than 5 m^3 of biogas. This research demonstrates that biogas can be produced in

below-ground digesters using aged beef cattle manure if the solids content is less than or equal to 40 percent, but that year-round biogas production is not feasible unless the digesters are heated or insulated.

INTRODUCTION

More than seven million beef cattle are fed each year in feedyards in the Southern High Plains area (SPS, 1999), producing 1.6×10^{10} kg of as-excreted (fresh) manure annually (Parker et al., 1997). Most of these cattle are fed in feedyards with capacities larger than 20,000 animals. Beef cattle at most large feedyards are raised on earthen-surfaced pens. Unlike many swine and dairy operations that utilize water-based manure collection systems (i.e. flush, scrape, or pull-plug systems), most beef cattle feedyards use a dry manure collection system. At beef feedyards, animals deposit manure directly on the open lot surface, and the manure is scraped and removed every 120 to 365 days. During this period the “aged” manure dries considerably. While the average total solids content of fresh feedyard manure is 24 percent (Auvermann et al., 2000; ASAE, 1999a), manure scraped from open-lot beef cattle feedyards has a total solids content of 55 to 90 percent, much drier than the waste in swine and dairy operations. The dry manure removed from beef feedyards is typically land applied as a source of fertilizer. Manure is sometimes stockpiled for short-term storage prior to land application. Because methane is a greenhouse gas, there has been a concern with potential methane production from manure in the stockpiles. Little data has been collected on the potential methane production from the stockpiled manure.

In a recent evaluation of manure value in the Southern High Plains area, the value of the potential energy from biogas exceeded the value of using the manure for its fertilizer equivalence (Parker et al., 1997). Biogas is produced during the decomposition of organic material under anaerobic conditions. Biogas is comprised of 55-70 percent methane (CH_4) and 30-45 percent carbon dioxide (CO_2) with traces of hydrogen sulfide, nitrogen, hydrogen, and carbon monoxide (Voermans, 1985). Biogas can be used as a substitute for natural gas for heating and producing electricity (Raab, 1985; Voermans, 1985).

The anaerobic breakdown of cattle manure to form biogas is accomplished by three types of bacteria, 1) hydrolytic, 2) transitional, and 3) methanogenic. In the first steps of production, hydrolytic bacteria reduce large macromolecules (proteins, fats, carbohydrates) to smaller molecules such as amino acids, sugars, acids, and alcohols. Transitional bacteria further reduce these molecules into acetic acid, H_2 and CO_2. The final step of breakdown is accomplished by methanogenic bacteria, which reduce the molecules into methane (CH_4) and carbon dioxide (CO_2) (Engler and McFarland, 1997). Hansen et al. (1998) state that acetate-utilizing methanogens are responsible for 70 percent of methane produced in a biogas reactor.

Biogas production is a temperature-dependent process (Misra et al., 1992). Biogas has been produced in psychrophilic (-10 to 30°C), mesophilic (20 to 50°C), and thermophilic (35 to 75°C) temperatures ranges (Chynoweth, 1998; Safley et al., 1992; Tchobanoglous and Burton, 1979). It is difficult to predict biogas production rates in the psychrophilic and lower mesophilic temperature ranges. Based on temperature alone, Hilhorst et al. (2001) predicted a 66 percent reduction in methane emissions whenever the temperature dropped from 20 to 10°C. Safley and Westerman (1992) showed that between the temperature of 8 to 30°C, a 1°C rise in temperature increased methane yield by about 0.009 m^3 per kg of volatile solids.

Most anaerobic digesters are designed to operate in the mesophilic and thermophilic temperature ranges. There are advantages and disadvantages of each temperature range. Mesophilic temperatures are more stable than thermophilic because they inhibit the production of excessive free ammonia, which can destroy the bacteria vital for anaerobic digestion (Fedler and Day, 1985; Hashimoto et al., 1981; Angelidaki & Ahring, 1994). Advantages of thermophilic temperatures include destruction of pathogenic bacteria and higher loading rates. A disadvantage of mesophilic and thermophilic digestion is that an external heat source is required to maintain design operating temperatures.

Traditionally, several types of anaerobic digesters have utilized manure, including complete mix, fixed film, and plug flow (Schulte & Luis, 1983; Rivard et al., 1989; Miner et al., 2000). Most completely mixed and fixed film digesters are designed for 3 to 12 percent total solids (Miner et al., 2000; Moser and Mattocks, 2000). Plug flow digesters are designed to operate at 8 to 12 percent total solids, and are commonly used with dairy waste (Miner et al., 2000; Moser and Mattocks, 2000). Complete mix, fixed film and plug flow digesters are well adapted to water-based manure collection systems, such as scrape, flush and pull-plug systems common in many swine and dairy operations. However, they are not well adapted to dry manure collection systems typical of most open-lot beef cattle feedyards. Jewell (1981) was one of the first to use the term "dry methane fermentation" which refers to digestion with little or no dilution of waste. Schulte and Luis (1983) evaluated biogas production of "dry" beef cattle manure at solids contents of 10, 20, 30 and 40 percent at 35°C in what they called a "tumble mix" system. They were unable to obtain steady state conditions at 40 percent solids. Kitamura et al. (2001) studied biogas production of dry dairy manure at solids content between 9.5 and 14.7 percent in a similar mixing apparatus that they called a "rotational drum system."

During the manure collection process at beef cattle feedyards, foreign solids such as soil and rocks often become mixed with the manure. High quantities of foreign solids cause problems in conventional completely mixed, fixed film, and plug flow digesters. One of the greatest deterrents to the use of biogas as an energy source has been the high cost of building and maintaining digesters (Hills, 1980; Rivard et al., 1989). Of eight biogas digesters installed at beef cattle feedyards, none are operating today (SERI, 1985). The failure of conventional digesters, combined with a limited water supply, leaves an opportunity for exploring other options for producing biogas with beef cattle manure in the arid regions of the United States.

Given an initial solids content of 55 percent, about 6.5 kg of water must be added to each kg of manure to achieve a slurry with 12 percent solids, and 18.2 kg of water to achieve a slurry with 5 percent solids. Water is a precious commodity in most semiarid areas, so the addition of large amounts of water to beef cattle manure for digestion is neither desirable nor economically feasible. Also, the cost for transporting and land applying the spent slurry at digestion completion increases drastically with decreasing solids content.

Biogas generation is of interest because of its energy potential, however, the methane in biogas is a greenhouse gas making biogas an environmental concern (ASAE, 1999). It has been estimated that 6 to 10 percent of all anthropogenic methane emissions are from animal waste (USEPA, 1992). In the U.S., about 36 percent of all agricultural related methane emissions come from anaerobic lagoons, and about 7 percent from dry open-lot feeding operations (USEPA, 1992). Sources of methane emissions from open-lot feeding operations include open-lot pens, runoff storage ponds, and manure stockpiles. These sources are typically aerobic by design, however, after extended precipitation events they may become anaerobic for a short time. Little data exists on methane production from manure associated with open-lot feeding operations, either from the pen surface, the storage pond, or the manure stockpile.

A research project was conducted to evaluate biogas production using aged beef cattle manure scraped from open lots. The specific objectives of this research were to 1) determine the highest solids content at which biogas could be produced, 2) determine the biogas yield at this solids content, 3) determine how temperature and solids content affect biogas production in a field-scale unheated, batch-type anaerobic digester, and 4) determine the potential for methane generation and associated greenhouse gas concerns from manure stockpiled at beef cattle feedyards.

MATERIALS AND METHODS

The research consisted of a laboratory experiment and a field experiment. The laboratory experiment was conducted in the Environmental Agriculture Lab at West Texas A&M University's Killgore Research Center. The field experiment was conducted at the WTAMU Research Feedlot located 10 km east of Canyon, Texas. Manure for both the laboratory and field phases was collected from a large commercial beef cattle feedyard during pen cleaning. Because the manure for the two phases was collected at different times, it had slightly different physical properties. The manure was tested for solids content by oven drying at 100°C for 24 hrs. Volatile solids (VS) content was measured using a muffle furnace at 500°C for one hour (ASAE, 1999b).

Laboratory Experiment

The manure removed from the commercial feedyard had an initial total solids content of 78.3 percent, initial dry basis VS content of 32.0 percent, and initial pH of 8.0. Other characteristics of the manure including nutrient concentrations are shown in Table 1. Manure in amounts of 40.0, 60.9, 81.2 and 86.5 g was placed with 115, 100, 80 and 50 ml of water, respectively, into 125 ml glass Erlenmeyer flasks to obtain total solids contents of 50, 40, 30, and 20 percent. The flasks were equipped with rubber stoppers and plastic tubing (0.6 cm O. D. polyurethane-Cole Parmer Instrument Company). There were three replications at each solids content. The flasks were maintained at 21°C throughout the experiment. Biogas was collected by water displacement in inverted 1 L Nalgene containers (figure 1). The volume of biogas produced in each container was recorded every few days for the duration of the 475 day project. Containers were replaced as they filled with biogas.

In the laboratory, biogas samples were analyzed for methane content using a Hewlett Packard GCD 1800A capillary GC/MS. A 1-ml gastight syringe injection was separated on an HP-PLOT Q (divinyl benzene/styrene) porous polymer capillary column (30 m x 0.32 mm x 20.0 μm). A 5-m uncoated retention gap was used to mate the column to the quadruple mass spectrometer detector. Total ion peak areas were calibrated with standard gas mixtures of methane and carbon dioxide. The GC/MS results closely matched those of the portable methane analyzer.

Field Experiment

Two below ground "landfill-type" digesters were constructed in Fall, 1998. Each digester measured 11 m x 11 m at ground level and was 1.8 m in depth with a 3 m x 3 m base and 2H:1V sideslopes (figure 2). Each digester had a capacity of 90 m^3. The digesters were lined on the bottom with a one-piece black ethylene propylene diene monomer (EPDM) geomembrane liner (Colorado Lining, Parker, CO). The first digester (digester 1) was filled with manure and water (40 percent total solids, initial VS= 32.0 percent), and capped on February 12, 1999. The manure used to fill digester 1 was the same manure that was used in the laboratory experiment (table 1). The second digester (digester 2) was filled with manure and water (50 percent total solids, initial VS= 41.9 percent) and capped on January 4-5, 2000. The manure used to fill digester 2 was from the same feedyard as the manure used in the laboratory experiment and to fill digester 1, however, because it was collected at a different time period it had different properties (table 1). A grid of perforated PVC pipe was placed at the top of each digester and routed to a common collection point to collect gas samples. The digesters were equipped with a data logger and thermisters (Unidata Starlogger Model 6004, Lake Oswego, OR) to monitor manure temperatures at a depth of 50 cm.

The digesters were capped with a 17 m square black EPDM geomembrane placed loosely over the top. The perimeter of the top membrane was placed in a 60 cm deep trench and covered with compacted soil. Biogas was collected for several days, inflating the geomembrane in a dome shape. The volume of biogas was determined by conventional surveying methods. To periodically collect biogas samples for methane concentration analysis, a tedlar bag was attached to the exit port.

Biogas samples were analyzed in the field using a GT Land Surveyor portable methane meter (Gastech, Newark, CA). The portable methane analyzer was equipped with catalytic compensation to measure combustible gases, and was calibrated against two calibration gases of 2.5 and 95 percent methane concentrations.

A composite manure sample, consisting of ten grab samples, was collected from both digesters at the completion of the experiment and analyzed for TS, VS, and various nutrients and salts.

Statistical Analyses

Statistical analyses were performed using SPSS 10.0 computer software. Analyses included one-way analysis of variance (ANOVA) and LSD comparisons at a significance level of 0.05.

Economic Analysis

An economic analysis was performed to determine the size of digester required to breakeven with construction costs. Benefit to cost (B:C) ratios were calculated using an excavation cost of \$1.00/m^3, installed liner cost of \$4.20/m^2. The biogas was assumed to be composed of 50 percent methane. A range of natural gas prices were used, ranging from a high of \$353/Mm^3 (January 2001) to the current of \$125/Mm^3 (April 2002). A square digester was used because it had the lowest material costs per unit digester volume. A variety of digester sizes were evaluated, all with sideslopes of 2 horizontal to 1 vertical. Digester lifespans of one-time and five-time use were evaluated. Costs for removal and land application of manure from the digester were not included in the analysis.

RESULTS AND DISCUSSION

Laboratory Experiment

Little biogas was produced at 50 percent total solids content. At 20, 30, and 40 percent total solids contents, biogas production began about 45 days after the manure was placed in the containers, and remained constant until about day 300, when it began to decrease (figures 3 and 4). Biogas production ceased completely after 450 days in all containers. Total biogas yields were 0.18, 0.21 and 0.19 L per gram volatile solids (VS) at solids contents of 20, 30, and 40 percent, respectively. Biogas yields were not statistically different among these volatile solids contents (table 2).

The highest mean biogas yield was 0.21 L/g VS at 30 percent solids content. In comparison, Hills (1980) reported a biogas yield of 0.18 L/g VS for high solids dairy manure, whereas Kottwitz and Schulte (1982) reported a biogas yield of 0.30 L/g VS for beef cattle manure in a high solids digestion process. In optimum conditions and with fresh manure, Safley et al. (1992) reported a maximum methane yield of 0.17 to 0.33 L CH_4/g VS for beef manure. Assuming that biogas is 50 percent methane, then the actual biogas yield would be double these values, or about 0.34 to 0.66 L/g VS for beef manure.

Concentrations of methane and other gases are presented in table 2. Typical methane concentrations were 52.5, 60.2, 58.9 and 6.7 percent for solids contents of 20, 30, 40, and 50 percent, respectively. These methane percentages are typical of those obtained for other manure sources (Safley et al., 1992; Hills, 1980; Hashimoto et al., 1981).

Field Experiment

The manure was warm when it was placed in digester 1 (25°C), a result of aerobic composting while stockpiled for two weeks before loading into the digester. The manure temperature dropped quickly after placement in the digester (figure 5). Digester 1 began biogas production on August 1, 1999, 170 days after it was loaded with manure. At this time, the manure temperature was 22°C and mean weekly air and soil temperatures were both 24°C. Manure temperatures increased during the summer months, a result of warmer ambient temperatures, peaking about August 1 at 22.4°C (figure 5). The lower limit of the thermister was 15.0°C so manure temperatures were not available below this value.

Biogas production ceased abruptly on October 23, 1999, when the manure temperature reached 15°C. During the 12-week period, digester 1 produced 1,510 m^3 of biogas. The pH of the manure in digester 1 was sampled a week after the cessation of biogas production in October, 1999. Three manure samples had a pH ranging from 6.98 to 7.26.

During the second summer, biogas production began again in digester 1 on July 14, 2000. Because of a malfunction in the datalogger, manure temperatures were not available for June and July. However, mean weekly air and soil temperatures were 27 and 26°C, respectively, in the middle of July, 2000. Biogas production ceased in mid-October, 2000. The manure temperature at this time was 21°C. During the second summer, 920 m^3 of biogas was produced, for a total of 2,430 m^3 of biogas produced in digester 1 over the two summers. No biogas was produced during the third summer. Given the similar rapid onset and cessation of biogas production over both summers, it seems likely that temperature was the controlling factor for biogas production. Biogas was not produced whenever the temperature dropped below 15°C. The methane concentration of the biogas in digester 1 was 40 percent the first time it filled, then ranged from 49 to 52 percent the duration of the experiment.

Less than 5 m^3 of biogas was produced in digester 2, which was loaded with manure at 50 percent total solids. Apparently the solids content was too high, which corresponds with the finding of no significant biogas production at 50 percent solids in the laboratory study.

The total volatile solids content in digester 1 was $1.55\text{x}10^7$ g. The total volume of biogas produced in digester 1 was $1.51\text{x}10^6$ L during the first summer and $9.2\text{x}10^5$ L during the second summer, which equates to a biogas production rate of 0.16 L/g VS. This is slightly less than the average biogas yield of 0.19 L/g VS measured in the laboratory experiment at 40 percent solids content.

The total solids concentration in digester 1 increased, indicating a loss of water, while the total solids concentration in digester 2 stayed the same (table 1). The volatile solids concentrations decreased in both digesters. This makes sense for digester 1, which produced a significant amount of biogas, however it does not make sense for digester 2, which produced very little biogas. The nutrient and salt concentrations presented in table 1 are representative of manure conditions in the digesters, but care should be given before using these concentrations for mass balance purposes. While every attempt was made to obtain a representative composite sample of the entire digester, there is no doubt that variations exist between locations in the digester possibly, a result of internal temperature differences and variation in initial manure quality. All concentrations in table 1 are expressed on a wet weight basis, and the mass of the manure changed during digestion because of loss of volatile solids (carbon loss). This might explain why some of the parameters actually increased in concentration. This does not imply that nutrients or salts were produced, only that the concentration increased because of a loss of organic matter (i.e. the total weight decreased).

Economics

The biogas yield in the field experiments was 0.04 L per dry gram of manure. Assuming all manure removed from feedyards in the Southern High Plains had 79 percent solids, then $3.1\text{x}10^9$ kg of manure would be available annually. The maximum potential biogas production from this manure is therefore $1.2\text{x}10^{11}$ L per year.

Natural gas prices more than quintupled between between January 1999 (\$64/Mm^3) and January, 2001 (\$353/Mm^3). Natural gas prices decreased to about \$125/Mm^3 as of April, 2002. An increase in fuel values usually sparks an increase in anaerobic digestion of beef cattle manure. However, most operations will not consider digesters unless there is a positive return on investment, or if there are some other side benefits such as odor reduction.

Results of the economic analysis show that a small digester like the one used in this research is not economically feasible for one-time use, with a benefit to cost (B:C) ratio ranging from 0.08 (based on natural gas price of \$125/Mm^3) to 0.22 (natural gas price of \$353/Mm^3) (table 3). Economics could be improved by building a larger digester. If the natural gas price of \$353/Mm^3 is used, and the digester is used only once, then several digester sizes are possible to achieve a B:C ratio of 1.0. For example, for a 4 m deep digester, the minimum top width is 45.4 m, and for a 6 m deep digester, the minimum top width is 37 m. If a more recent natural gas price of \$125/Mm^3 is used, then a digester must be at least 14 m deep to achieve a B:C ratio greater than 1.0. A drawback to use of large landfill-type digesters is that special equipment such as draglines or extendable backhoes are required to remove manure.

Economics could also be improved by using the digester more than once. Because the manure is too thick to pump, manual manure removal is necessary, so the entire top liner must be removed. It is difficult to reuse an EPDM liner, so a new top liner must be purchased each time the digester is filled. The bottom liner can be reused if care is taken to avoid damaging it during manure removal. If the digester were used five times, then the B:C ratios would about double (table 3).

An option to using a geosynthetic bottom liner would be to use a clay liner. The clay liner would cost slightly more than the geosynthetic liner, and could be used repeatedly without the risk of damaging the liner, thus improving the long-term economics of the system.

It is apparent that additional engineering solutions must be developed before an unheated, high solids digester will be feasible. These engineering solutions should include development of methods for land application of the digested manure. Most beef feedlot manure is currently surface applied as a solid (80 percent solids, 20 percent moisture) using manure spreaders. A change to a liquid slurry application system would require significant costs in the purchase of new land application equipment. Costs to remove and land apply the digested manure should be evaluated before a high solids digester is constructed.

CONCLUSIONS

The following conclusions were drawn from this research:

1. At a constant 21°C in the laboratory, biogas was produced at solids contents of 20, 30, and 40 percent, but not at 50 percent. The maximum solids content for successful anaerobic digestion of aged beef cattle manure was 40 percent.

2. The ultimate biogas yield at 40 percent solids content and 21°C was 0.19 L/g VS under controlled laboratory conditions. There were no significant differences among biogas yields at 20, 30, and 40 percent solids contents.

3. The biogas yield in the field digester was 0.16 L/g VS at 40 percent solids content. Little biogas was produced in the digester with 50 percent solids. No biogas was produced in the field digester during the winter months. Biogas production began in the summer months whenever the manure temperature reached 22°C, and ceased in the fall whenever the manure temperature dropped below 15°C. Biogas production occurred over two consecutive summers.

4. Because most manure is stockpiled in open-lot animal feeding operations at less than 50 percent moisture content, it seems unlikely that methane will be produced from the stockpile.

ACKNOWLEDGEMENTS

This project was funded by a grant from the Western Regional Biomass Energy Program (WRBEP), Lincoln, Nebraska.

DISCLAIMER

The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-ARS or WTAMU.

REFERENCES

Angelidaki, I. and B.K. Ahring. 1994. Anaerobic thermophilic digestion of manure at different ammonia loads:effect of temperature. *Water Research* 28:727-731.

ASAE. 1999a. Manure production and characteristics. ASAE Standard D384.1, St. Joseph, Mich.:ASAE.

ASAE. 1999b. Uniform terminology for rural waste management. ASAE Standard S292.5, St. Joseph, Mich.:ASAE.

ASAE. 1999. Energy and Biomass Engineering, CIGR Handbook of Agricultural Engineering, Volume V. St. Joseph, Mich.:ASAE.

Auvermann, B.W., L.A. McDonald and K. Heflin. 2000. Unpublished data. Regional manure survey, Playa Basin 319(h) project, Amarillo, TX.

Chynoweth, D.P., A.C. Wilkie and J.M. Owens. 1998. Anaerobic processing of piggery waste: a review. ASAE Paper No. 98-4101. St. Joseph, Mich.: ASAE.

Engler, C.R. and M.J. McFarland. 1997. Dairy manure digestion research and demonstration project. In Proceedings of Workshop #1, Livestock Waste Streams: Energy and Environment, 64-68. Austin, TX: Texas Renewable Energy Industries Association.

Fedler, C.B. and D.L. Day. 1985. Anaerobic digestion of swine manure containing an antibiotic inhibitor. Proc. Fifth International Symposium on Agricultural Wastes, 523-530. St. Joseph, Mich.:ASAE.

Hansen, K.H., I. Angelidaki and B.K. Ahring. 1998. Anaerobic digestion of swine manures: inhibition by ammonia. *Water Research* 32(1):5-12.

Hashimoto, A.G., V.H. Varel and Y.R. Chen. 1981. Ultimate methane yield from beef cattle manure: effect of temperature, ration constituents, antibiotics, and manure age. *Agricultural Wastes* 3(4):241-256.

Hilhorst, M.A., H.C. Willers, C.M. Groenestein and G.J. Monteny. 2001. Effective strategies to reduce methane emissions from livestock. ASAE Paper No. 01-4070. St. Joseph, Mich.: ASAE.

Hills, D.J. 1980. Methane gas production from dairy manure at high solids concentration. *Transactions of the ASAE* 23(1):122-126.

Jewell, W.J. 1981. Crop residue conversion to biogas by dry fermentation. ASAE Paper No. 81-3573. St. Joseph, Mich.: ASAE.

Kitamura, Y., W. Jiang, N. Ishizuka and T. Liang. 2001. Rotational drum reactor system for dry methane fermentation. ASAE Paper No. 01-6016. St. Joseph, Mich.:ASAE.

Kottwitz, D.A. and D.D. Schulte. 1982. Tumble-mix anaerobic digestion of dry beef manure. ASAE Paper No. 82-3596 St. Joseph, Mich.:ASAE.

Miner, J.R., F.J. Humenik and M.R. Overcash. 2000. Managing livestock wastes to preserve environmental quality. Ames, IA: Iowa State University Press.

Moser, M.A. and R.P. Mattocks, 2000. Benefits, costs and operating experience at ten agricultural anaerobic digesters. In *Proc. of the 8th Int. Symposium on Animal, Agricultural and Food Processing Wastes,* ed. J.A. Moore, 346-352. St. Joseph, MI: ASAE.

Misra, U., S. Singh, A. Singh, and G.N. Pandey. 1992. A new temperature controlled digester for anaerobic digestion for biogas production. *Energy Conservation Management* 33:983-986.

Parker, D.B., B.W. Auvermann, B.A. Stewart and C.A. Robinson. 1997. Agricultural energy consumption, biomass generation, and livestock manure value in the Southern High Plains. In Proceedings of Workshop #1, Livestock Waste Streams: Energy and Environment. Austin, TX: Texas Renewable Energy Industries Association.

Raab, J. 1985. Biogas resources developed in Oregon. *Public Works* 116:64-65.

Rivard, C.J., M.E. Himmel, T.B. Vinzant, W.S. Adney, C.E. Wyman, and K. Grohmann. 1989. Development of a novel laboratory scale high solids reactor for anaerobic digestion of processes municipal solid waste for the production of methane. *Applied Biochemistry and Biotechnology* 20:461-478.

Safley, L.M. and P.W. Westerman. 1992. Performance of a low temperature lagoon digester. Bioresource Technology 41:167-175.

Safley, L.M., M.E. Casada, J.W. Woodbury and K.F. Roos. 1992. Global methane emissions from livestock and poultry manure. Washington, DC:United States Environmental Protection Agency.

Schulte, D.D. and V. Luis. 1983. Kinetic analysis of anaerobic fermentation of dry beef cattle manure. ASAE Paper No. 83-4057. St. Joseph, Mich.:ASAE.

SERI. 1995. Anaerobic digestion data base: Guide for operation and data analysis. Biomass Program Office, Solar Energy Research Institute. Golden, CO.

SPS. 1999. Cattle-Feeding Capitol of the World - 1999 Fed Cattle Survey. Amarillo, TX: Southwestern Public Service Company.

Tchobanoglous, G. and F.L. Burton. 1979. Wastewater Engineering-Treatment, Disposal and Reuse. McGraw-Hill, Inc., New York, NY.

USEPA. 1992. Global methane emissions from livestock and poultry manure. EPA/400/1-91/048. Washington, DC.:United States Environmental Protection Agency.

Voermans, J.A.M., 1985. Biogas production on livestock farms. Proc. Fifth International Symposium on Agricultural Wastes, 132-137. St. Joseph, Mich.:ASAE.

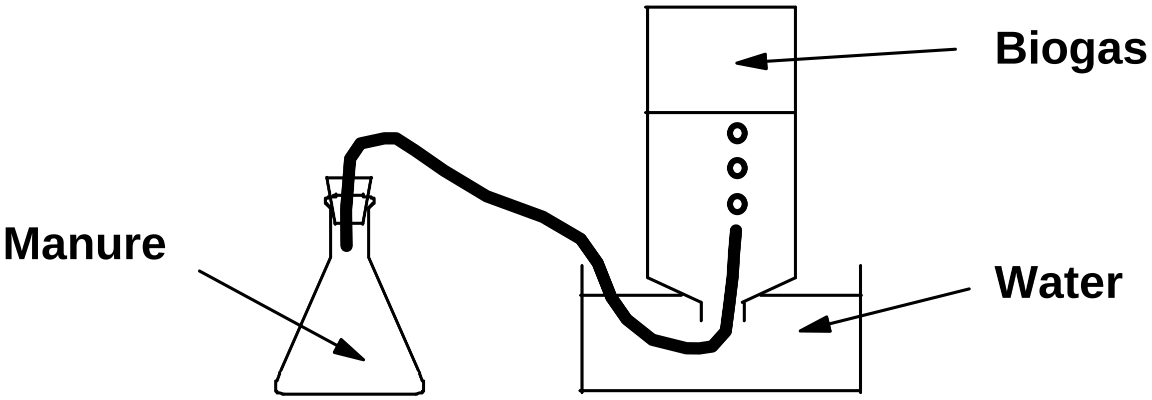

Figure 1. Schematic of small-scale batch type digester and biogas collection apparatus used in the laboratory experiment.

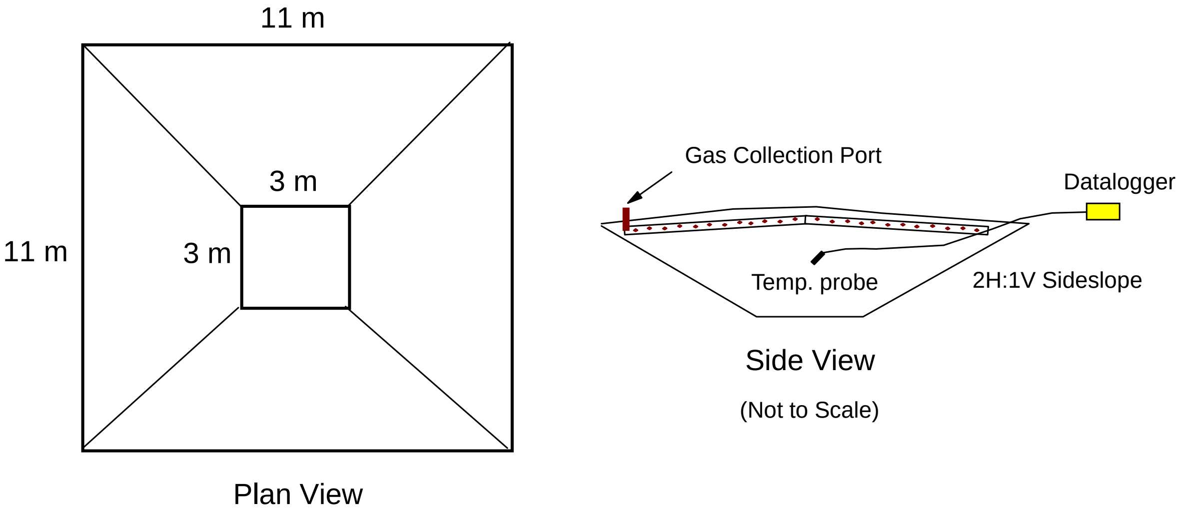

Figure 2. Schematic of unheated, below-ground batch digester used in the field experiment.

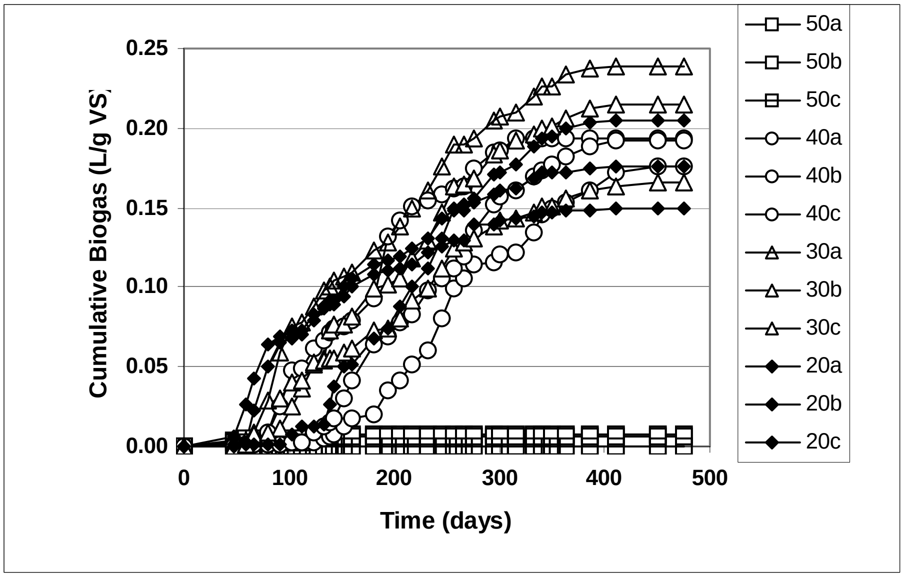

Figure 3. Laboratory biogas production rates at solids contents of 20, 30, 40, and 50 percent. There were 3 replications of each solids content.

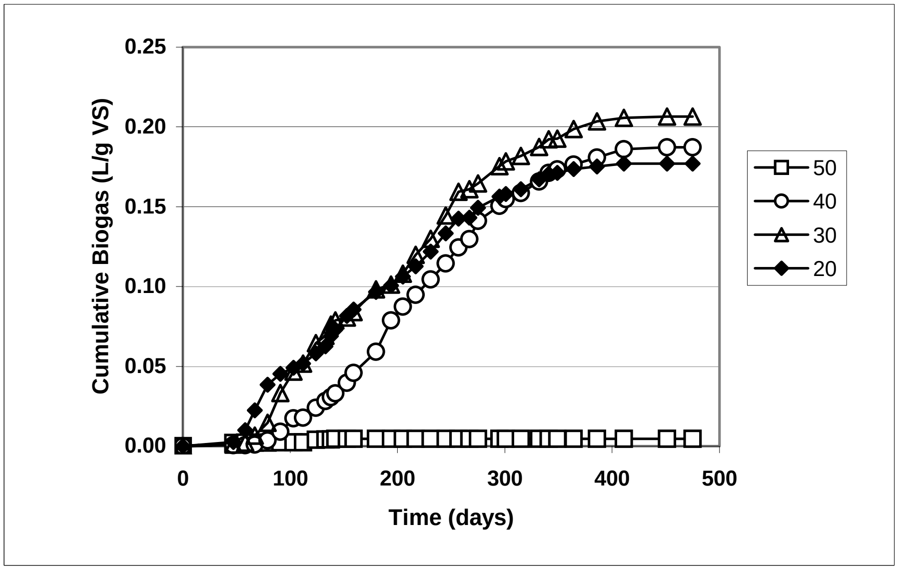

Figure 4. Mean laboratory biogas production rates at solids contents of 20, 30, 40, and 50 percent. Each point is the average of 3 replications.

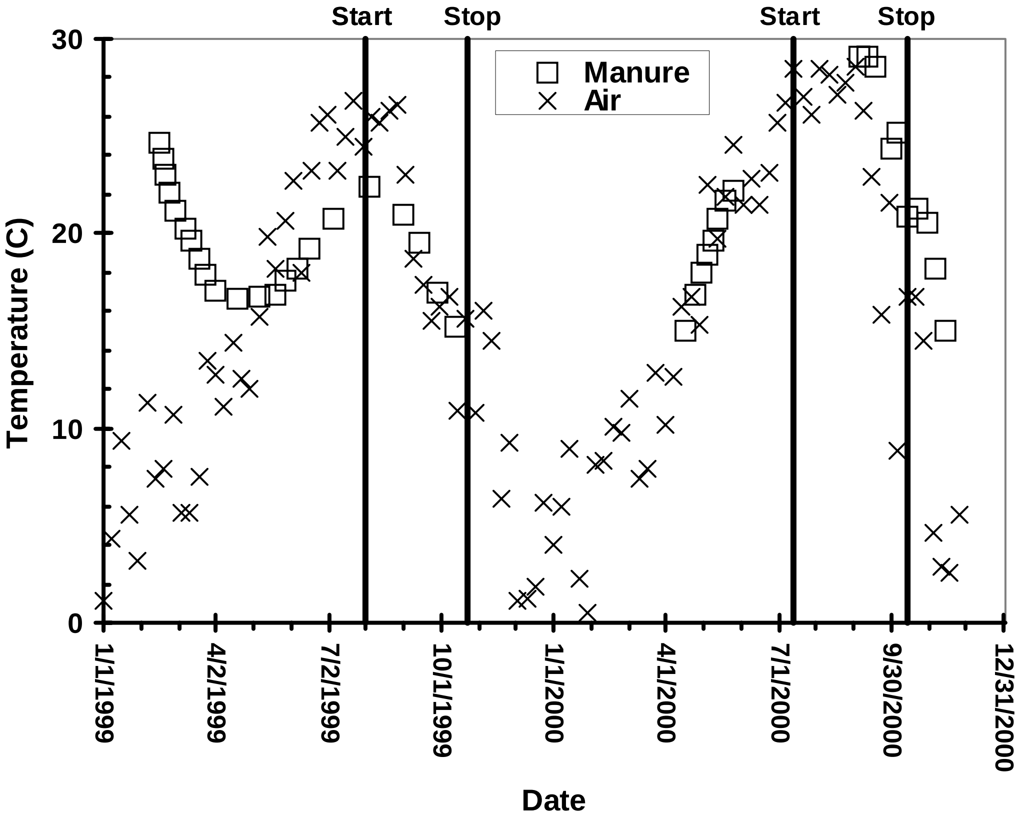

Figure 5. Temperature of manure in digester 1 compared to average weekly ambient air temperature. Vertical lines are start and stop dates for biogas production. The lower limit of the manure thermister was 15°C.

Table 1. Manure characteristics before and after anaerobic digestion in the field digesters. The initial manure used in digester 1 was the same as used in the laboratory experiment.

	Digester 1		Digester 2	
	Initial	Final	Initial	Final
TS (%)	40.0	47.7	50.0	50.3
VS (%)	32	25.2	41.9	23.2
Organic N (%)	1.32	2.21	na	1.11
NH_4-N (mg/kg)	836	3125	na	2164
NO_3-N (mg/kg)	19.9	3.4	na	3.2
Total N (%)	1.41	2.53	na	1.33
P (%)	0.51	0.91	na	0.54
K (%)	1.37	3.21	na	1.45
S (%)	0.52	0.68	na	0.5
Ca (%)	3.95	2.88	na	2.56
Mg (%)	0.88	1.03	na	0.67
Na (%)	0.31	0.84	na	0.34
VFAs (mg/kg)	8131	7493	na	8959
pH	8.0	8.4	na	8.4

na=not analyzed

Table 2. Biogas production rates and other gas concentrations.

Solids Content (%)	Biogas Production Rate		Typical Gas Concentrations (%)			
	Mean (L/g VS)	St. Dev.	Methane	Carbon Dioxide	Water	Other Gases
20	0.18 b	0.028	52.5	32.8	3.0	11.7
30	0.21 b	0.037	60.2	27.0	2.1	10.7
40	0.19 b	0.010	58.9	28.4	5.0	7.7
50	0.005 a	0.004	6.7	23.6	2.5	67.2

Using LSD comparisons, mean biogas production rates with same letters are not significantly different (α=0.05).

Table 3. Economic analysis showing benefit to cost (B:C) ratios for a variety of digester sizes at two natural gas prices and one-time or five-time use lifespan.

Top Width (m)	Depth (m)	Volume (m^3)	Natural Gas Price ($\$/\mathrm{Mm}^3$)	Biogas Value ($)	Liner Cost ($)	Excavation Cost ($)	B:C Ratio
10.4[ab]	1.8	90	125	152	1840	90	0.08
10.4[ab]	1.8	90	353	430	1840	90	0.22
10.4[ac]	1.8	90	125	760	5304	90	0.14
10.4[ac]	1.8	90	353	2,145	5304	90	0.40
45.4[b]	4.0	5,680	125	9,554	21,298	5,680	0.35
45.4[b]	4.0	5,680	353	26,980	21,298	5,680	1.00
45.4[c]	4.0	5,680	125	47,769	62,296	5,680	0.70
45.4[c]	4.0	5,680	353	134,899	62,296	5,680	1.98
37.0[b]	6.0	4,038	125	6,791	15,130	4,038	0.35
37.0[b]	6.0	4,038	353	19,179	15,130	4,038	1.00
37.0[c]	6.0	4,038	125	33,957	43,371	4,038	0.72
37.0[c]	6.0	4,038	353	95,896	43,371	4,038	2.02
36.4[b]	8.0	4,012	125	6,748	15,052	4,012	0.35
36.4[b]	8.0	4,012	353	19,055	15,052	4,012	1.00
36.4[c]	8.0	4,012	125	33,738	42,472	4,012	0.73
36.4[c]	8.0	4,012	353	95,277	42,472	4,012	2.05
555.0[b]	14.0	3,891,865	125	6,545,703	2,656,061	3,891,865	1.00
555.0[b]	14.0	3,891,865	353	18,485,064	2,656,061	3,891,865	2.82
555.0[c]	14.0	3,891,865	125	32,728,513	7,905,742	3,891,865	2.77
555.0[c]	14.0	3,891,865	353	92,425,321	7,905,742	3,891,865	7.83

[a] Research digester.

[b] Digester used one time.

[c] Digester used five times.