UTILIZATION OF BYPRODUCTS FROM HUMAN FOOD PRODUCTION AS FEEDSTUFFS FOR DAIRY CATTLE AND RELATIONSHIP TO GREENHOUSE GAS EMISSIONS AND ENVIRONMENTAL EFFICIENCY

K. L. Russomanno, M. E. Van Amburgh, and R.J. Higgs
Department of Animal Science
Cornell University

INTRODUCTION

As a means for providing cost effective and environmentally sustainable feed to dairy cattle, byproducts from both human food production and other industrial processes have traditionally been used and are being used at higher levels to replace more expensive sources of nutrients. Industries' manufacturing products such as ethanol and seed oils accumulate waste (i.e. distiller's grains, soybean meal, canola meal) requiring disposal. Byproducts can and have served as economical alternative sources of nutrients for dairy cows and by utilizing them, the dairy industry has significant potential to reduce the environmental impact of human food production and provide financial sustainability of the industry itself by reducing dependence on expensive primary crop sources.

For example, total world citrus production averaged approximately 64.9 billion kilograms per year from 2000 through 2003 (USDA, 2003). Citrus byproducts generated during juicing such as citrus pulp contain a variety of energy substrates and are fed to lactating dairy cattle as a high energy feed (Bampidis and Robinson, 2006). According to Mowrey and Spain (1999), 21.7 % of lactating dairy cattle in the southeast region of the country were receiving citrus pulp in dairy rations. Similarly, Mowrey and Spain (1999) also estimated that 13.3 and 16.7 % of lactating dairy cattle were fed almond hulls in the northwest and southwest area of the country, respectively. Studies analyzing the nutritional value of almond hulls showed similar performance in cattle receiving rations with almond hulls substituted for alfalfa (Aguilar et al., 1984).

The United Nations census is forecasted to reach 9.5 billion people by the year 2070 (UN, 2005). If the dairy industry is to continue producing enough milk, cheese and other products to feed the growing population it must increase the total milk yield of the American dairy herd by 23.7 million kilograms by the year 2040 while depending on finite amounts of land and natural resources (Capper et al., 2008b). The increase in population will result in increased production of plant and vegetable based foods and other byproducts and a growing need for sustainable disposal methods.

Understanding the impacts of byproduct feeding on greenhouse gas emissions is an important consideration for both the dairy industry and the industries that produce the byproducts. The objective of this paper is to evaluate predicted carbon dioxide and methane emissions in relation to byproduct inclusion of dairy cattle diets gathered from around the country. To do this, an equation to predict CO_2 emissions from dietary ingredients and basic cow descriptions (Casper and Mertens, 2010) was added to the Cornell Net Carbohydrate and Protein System v6.1 (CNCPS v6.1; Fox et al., 2004, Tylutki et al., 2008, Van Amburgh et al., 2010). An extant equation for methane emission was already available within the model (Mills et al., 2003) and the combination allowed for the prediction of CO_2 equivalents without nitrous oxide.

For a discrete comparison, the predictions of gaseous emissions are compared to CO_2 emissions resulting from direct combustion of the byproducts, recognizing that this would be one possible route of disposal if not fed to cattle. There is little information about the carbon distribution from landfilling, use as fertilizer or other routes of disposal for the range of byproducts being considered. Thus, the simplest comparison to provide an estimate of the reduced environmental impact of utilizing byproducts from the human food system in dairy cattle for milk production was combustion. There are models being developed that include the agronomic aspects of carbon dioxide cycling (Chianese et al. 2009; Sejian et al. 2011).

It is important to recognize there is no single source of information about the amount of byproducts produced in the U.S. aside from a couple industry groups that maintain reasonable databases of production (e.g. CA Almond Board, http://www.almondboard.com), thus our approach was to request diets from practicing nutritionists and industry professionals around the country to populate the database.

MATERIALS AND METHODS

Data collection

Data for this study were collected from nutritionists and consultants from ten different states representing significant regions of dairy production. States included were AZ, CA, FL, ID, MI, NY, PA TX, VT, and WI. Adequate information was provided to enable an evaluation to be made in the Cornell Net Carbohydrate and Protein System v6.1 (CNCPS; Fox et al., 2004, Tylutki et al., 2008, Van Amburgh et al., 2010). The data included a complete set of diet ingredients, including chemical analysis of individual ingredients as well as a complete diet nutrition summary. In addition, values for average body weight (BW), dry matter intake (DMI), milk yield, milk fat and milk protein were provided with the diet as part of the data collections. For any production characteristics not provided (less than 10 data sets), default values of 650 kg, 3.6% and 3.1% were used for BW, milk fat, and milk protein, respectively. A default value of 3.0 for body condition score (BCS) was used as needed for CNCPS evaluations. Ninety-one diets from seventy different farms representing ten different states were compiled, and included a range of different byproducts (i.e. soy hulls, distillers grains, apple pomace, bakery waste, almond hulls), common forages (i.e. alfalfa, corn silage, sorghum silage and triticale) as well as protein feeds (i.e. soybeans, cottonseed, canola), Rumensin® and mineral supplements.

Diets were entered into a spreadsheet version of the CNCPS v6. Ingredients in the diets and the chemical composition were provided by the nutritionist, however, if ingredient information was not provided, the ingredients were selected from the CNCPS feed library. Using this approach, any values unavailable from the data set such as dry matter content (DM), crude protein (CP), soluble protein, (SP), sugars, starch, acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin and ash were drawn from CNCPS feed library values. In the event that a given feed was not available in the CNCPS feed library, the closest match was made with other available feeds and the nutritional values corresponding with the original feed were added to the spreadsheet.

In some instances, ingredients were provided without nutritional analysis and were also unavailable within the CNCPS feed library. These ingredients were compared to those available from the Dairy One Cooperative (Ithaca, NY) feed composition library, and mean values from the database for CP, SP, NDF, ADF, lignin and ash were entered into the spreadsheet. The feedstuff closest in nutritional composition within the CNCPS feed library was then selected, and the composition values from the Dairy One database were entered. For example, when provided with “culled carrots,” an ingredient unavailable within CNCPS, the Dairy One database was consulted. The accumulated mean values for “culled carrots” of 9.7% CP, 46.5% SP, 20.9% ADF, 24.0% NDF, 2.9% starch and 3.0% lignin were entered into the spreadsheet as the chemical characteristics of carrots and used in the rest of the analyses and were initially edited from the library values for potatoes. Unknown values were estimated using the procedure described by Higgs et al., (2012) and found in these proceedings. Once all of the ingredient and cattle information was entered, each diet was evaluated with the CNCPS and predictions were compiled. A simplified summary of the evaluation data set is found in Table 1.

Enteric Methane and Carbon Dioxide Predictions

Published equations for enteric methane and carbon dioxide emissions were incorporated into the CNCPS from Mills et al., (2003) and Casper and Mertens, (2010), respectively. These equations were utilized to convert the dietary data into quantitative carbon dioxide and methane emission values. The equations presented here only evaluate greenhouse gas emissions and not total carbon balance across a cow, thus milk and manure carbon is not accounted for in this study but the equations could be added to the CNCPS. The Casper and Mertens (2010) carbon dioxide equation was compared to another published and utilized equation from Kirchgessner et al., 1991 to verify that the predictions were similar and provide some assurance of a lack of bias.

The Mills et al., (2003) logarithmic approach was used to calculate methane emissions as a function of metabolizable energy intake (MEI). Using the Mitscherlich growth law equation form:

$$y = a - (a+b)e^{-cx}$$

Table 1**.** Summary of animal and diet characteristic of the dairy cattle diets evaluated in the CNCPS v6.1for this study[1].

Item	Mean	SD	Minimum	Maximum
Dietary Characteristic				
DMI (kg per cow/day)	25.0	2.1	18.5	29.5
ADF (%DM)	19.3	1.5	15.7	23.4
NDF (%DM)	24.5	3.2	16.1	31.6
CP (%DM)	17.1	1.3	14.7	23.2
Starch (%DM)	24.5	3.2	16.1	31.6
By-Products (%DM)	31.2	9.4	9.4	56.7
Animal Characteristic				
BW (kg)	647.6	43.2	440.0	754.3
Milk yield (kg/day)	41.0	4.2	29.5	53.1
Milk fat (%)	3.7	0.2	3.3	4.5
Milk protein (%)	3.6	0.1	2.8	3.2

[1] Information compiled from 91 diets from 70 different farms representing 10 different states.

where *a* and *b* are the maximum and minimum values of *y,* respectively, and *c* is the shape parameter for determination of the change of *y* upon increase of *x.* The application of relevant parameters allowed for a derived relationship between ME intake (MEI) and methane output (Mills et al., 2003). The mathematical representation of *c* was modeled as follows:

$$c = -0.0011 \times \left[\frac{\text{starch}}{\text{ADF}}\right] + .0045 \quad (\text{r}^2 = .97)$$

Setting *b* as zero, representing the minimum value of methane emission corresponding with zero MEI, and *a* as the maximum output value of 45.98 as determined by Mills et al., (2003), the following equation was derived for the purpose of predicting methane output based on MEI (MJ):

$$y = 45.98 - (45.98e^{(-(-.0011)\times\left[\frac{\text{starch}}{\text{ADF}}\right]+.0445)\times\text{MEI})})$$

To predict carbon dioxide output, a curvilinear relationship between DMI, milk yield and carbon dioxide emission established by Casper and Mertens, (2010) was used:

$$CO_2 = (821.3 + (126.0 \text{ x DMI}) - (1.18 \text{ x milk})) / 0.27$$

where CO_2 is expressed in kg/d, DMI in kg/d and milk in kg/d, respectively.

An additional equation presented by Kirchgessner et al. (1991) was also evaluated:

$$CO_2 = (-1.4 + (0.42 \times DMI) + (0.045 \times BW^{0.75}))/0.27$$

where CO_2 is expressed in kg/d, DMI in kg/d and BW in kg/d. respectively, and compared against that of Casper and Mertens, (2010).

Carbon Dioxide from Byproducts

All byproducts included in the diets provided were analyzed for the levels of inclusion (% total DM). This was calculated using a simple mass ratio of each byproduct to the total DM of the ration. These ratios were then used to estimate the CO_2 release as a direct result of byproduct consumption, eliminating any forages, minerals, or non-byproduct (NBP) concentrates. This estimation for CO_2 for an individual byproduct of interest, (BP_i) was made using the following model:

$$\%CO_2C(BP_i) = [821.3 + \left(126.0\ \times \sum DMI\right) - \left(1.18 \times \sum milk\right)] \times \frac{\sum BP_i}{\sum DMI}$$

where BP_i represents the *i*th byproduct, and DMI, milk and BP are all in measure of kilograms. The model equated for the carbon equivalents of carbon dioxide, so resulting values were divided by a factor of 0.27, or the molar mass ratio of carbon to carbon dioxide (12.01g/mol:44.01g/mol), respectively.

Methane from Byproducts

The estimation for CH_4 release as a direct function of BP inclusion was calculated using the model from Mills et al., (2003), adjusted for byproduct methane estimation:

$$\%CH_4(BP_i) = \left[45.98 - (45.98e^{-\left(-.0011\times\sum\left[\frac{starch}{ADF}\right]+.0445\right)\times\sum MEI)}\right]$$

where BP_i refers to the nutrients (starch, ADF and MEI) contained within the byproduct ingredients. Ration ingredients were separated on the basis of their identity as byproducts (BP) or non-byproducts (NBP). To satisfy the model, starch, ADF, and MEI were separated accordingly.

To calculate the amount of methane produced from the byproducts in a ration, the starch, ADF values and MEI in terms of MJ were taken from the CNCPS. The same procedure was applied to non-byproduct ingredients, and the resulting sum of methane emission was compared with the value calculated when starch, ADF, and MEI were instead correlated with the entire mixed ration. Deviation in the model was adjusted by addition of a scalar to maintain consistency between the sum of emission levels from the separated ration and the calculated emission directly from the complete, mixed ration.

To compare to the predicted fraction of methane release due to byproduct consumption to combustion values, methane values were expressed in terms of carbon dioxide equivalents. To convert byproduct related methane emissions to carbon dioxide equivalents, values were multiplied by a factor of 23, the accepted literature value for the global warming potential (GWP) of methane, relative to the standard 1 GWP for carbon dioxide (EPA, 2010).

Carbon Dioxide from Combustion

Carbon compositions of each byproduct was calculated using the equation of Adams et al., (1951) and ash content from Table 4.

$$\%C=\frac{(\%VS)}{1.8} \quad \text{where:} \quad \%VS=100-\%Ash$$

and VS = volatile solids, (attributing to carbon, oxygen and nitrogen,) Ash = mineral elements that will not oxidize upon combustion and C = carbon.

Total carbon of each byproduct in a given ration was summed and CO_2 release determined stoichiometrically to allow a comparison between different disposal methods.

Statistical Analysis

A mixed model using the restricted maximum likelihood (REML) procedure of SAS Institute (2010) was used to analyze the data using the model

$$Yij = \mu + U_{ij} + e_{ij}$$

where Yij is the expected outcome using the *i*th data point, μ is the mean value of the independent variable, U_{ij} is the random effect, (measuring the difference between the mean and the selected value), and e_{ij} is random error. More information on this approach can be found in St-Pierre (2001). Predicted outcomes from the model were used to estimate the effect of random error on the data set when possible, and also to illustrate the accuracy and precision of correlations and trends without deviation from possible sources of error. Mean squared prediction errors (MSPE) were used to quantify the variation in the data set. The R^2 values were determined using JMP, and were applied to the original data trends to characterize more accurate relationships.

RESULTS

Carbon Dioxide and Methane Emissions

Predicted CO_2 emissions using either Casper and Mertens (2010) or Kirchgessner et al., (1991) were similar (Table 2). We chose to use the equation from Casper and Mertens (2010) because it was easily integrated into the CNCPS and the studies used to develop the equation encompassed a wide range of dry matter intake and milk yields from 1,252 individual cattle respiration calorimetric trials and were the foundation of the energy metabolism system used in the U.S.

Table 2. Comparison of CO_2 emissions from dairy cows between two published prediction equations.

	(Casper and Mertens, 2010)	(Kirchgessner et al., 1991)
	CO_2 (g/cow/d)	
Mean	14,281	14,775
SD	1,181	1,244
Minimum	9,172	9,059
Maximum	16,429	17,187

Total emission of CO_2 per cow was positively related to total milk yield (Figure 1; $R^2 = 0.69$). However, CO_2 emissions per kilogram of milk as a function of milk yield (kgCO_2/kg milk) resulted in a negative relationship, ($R^2 = 0.81$; Figure 2) and is similar to the data described by Capper et al., (2008b) and others when considering dilution of maintenance effects. The average value of CO_2 emission per unit of milk yield was 0.353 kg CO_2/kg of milk, with minimum and maximum values of 0.283 and 0.423 kg CO_2/kg milk, respectively (Table 4). The mean prediction of CO_2 (kg) per kg of byproducts was 0.05 and the correlation between CO_2 emission and inclusion of byproduct as a proportion of the total DMI was high ($R^2 = 0.81$; Figure 2).

Table 3. Predicted carbon dioxide and methane release based on the total amount of dry matter consumed (DMI), byproduct inclusion (kg) and as a ratio of the milk yield.

Variable	Mean	SD	Minimum	Maximum
DMI				
kg CO_2/kg DMI	0.576	0.011	0.557	0.618
kg CH_4/kg DMI	0.024	0.001	0.021	0.027
Byproduct				
kg CO_2/kg BP	0.050	0.018	0.029	0.117
kg CH_4/kg BP	0.002	0.001	0.001	0.005
Milk Yield				
kg CO_2/kg milk	0.353	0.031	0.283	0.423
kg CH_4/kg milk	0.014	0.001	0.012	0.018

Methane emissions per kg DMI ranged from 0.021 to 0.027 with a mean of 0.024 kg (Table 3). Methane emissions were positively correlated with milk yield (slope = 0.004; R^2 = 0.68; Figure 3) but negative correlated when expressed as a function of milk yield (slope = -0.26; R^2 = 0.88; Figure 4).

The average byproduct content of the diets analyzed was 31.3% ration DM with a minimum and maximum 12.7% and 56.7%, respectively The five byproducts that contributed the most to overall DM, in increasing order were corn gluten feed (dry) (2.08%), corn ethanol distillers (2.63%), soybean meal (47.5 solvent) (3.45%), whole (fuzzy) cottonseed (4.23%), and solvent- extracted canola meal (4.24%).

The data in Table 4 shows a detailed breakdown of all byproducts accumulated in collected rations, including a percent total DM value, indicating mass of the particular byproduct as a ratio of the DM content of the data set. The percent total DM represents relative utilization and incorporation of each individual byproduct across the dataset.

Table 4. Macro nutrient description and inclusion rates of byproducts in diets provided for this study. Any feed description (n = 4) not found in the feed library of the Cornell Net Carbohydrate and Protein System (CNCPSv6.1) was taken from the feed database from Dairy One Cooperative Inc.

By Product	DM (%)	CP	ADF	NDF	Starch	Ash	% Total DM
Almond Hulls 28 NDF	87	5.9	30.5	36.3	2.9	7.4	1.8
Almond Hulls 33 NDF	87	6.0	33.2	41.7	2.6	6.8	0.3
Almond Hulls 36 NDF	87	6.1	47.4	54.1	3.1	4.0	0.1
Almond Hulls 42 NDF	87	5.9	10.9	20.9	4.2	3.2	0.7
Apple Pomace	29	9.1	4.6	10.5	46.3	4.1	0.0
Bakery Blend	92	13.3	7.8	22.0	52.3	3.0	0.2
Bakery By Product	95	13.0	7.8	22.0	52.3	3.0	0.4
Barley Grain Flakes	88	12.5	26.6	43.6	5.0	11.9	0.1
Barley Grain Ground	88	12.5	25.1	36.8	3.0	12.2	0.2
Barley Malt Sprouts	93	24.6	21.1	30.1	2.6	7.3	0.1
Beet Pulp Dry 40 NFC	91	9.8	9.1	17.2	12.9	2.7	0.2
Beet Pulp Wet 34 NFC	23	9.8	7.6	16.2	14.7	5.3	0.1
Blood Meal	90	93.0	0.0	0.0	0.0	0.0	0.3
Brewer’s Grain Wet	25	29.0	20.4	27.7	2.6	8.0	0.4
Candy By Prod High Fat	89	11.7	5.5	15.5	49.0	3.6	0.0
Candy By Prod Low Fat	89	10.6	17.5	23.9	4.3	6.9	0.2
Canola Meal Expelled	90	36.0	16.0	33.6	5.5	5.9	1.0
Canola Meal Solvent	90	41.5	13.8	40.1	4.9	5.5	4.2
Cereal Blend	93	11.8	17.5	23.9	4.3	6.9	0.0
Cherry Juice	21	6.9	40.4	47.7	5.9	3.5	0.0
Citrus Pulp Dry	89	7.3	11.7	36.7	14.7	6.8	0.4

Table 4. *Continued.*

By Product	DM (%)	CP	ADF	NDF	Starch	Ash	% Total DM
Corn Cob	92	4.6	0.0	0.0	0.0	0.0	0.3
Corn Dist. Ethanol	89	30.3	3.1	13.9	5.9	9.0	2.6
Corn Dist. Medium Spirits	91	30.4	16.3	32.0	3.7	5.3	0.1
Corn Dist. Solubles	40	21.7	5.3	7.1	16.2	3.5	0.4
Corn Dist. Wet	32	32.0	25.0	45.0	0.5	5.0	0.3
Corn Gluten Feed dry	90	25.3	0.2	0.5	15.7	15.3	2.1
Corn Gluten Feed wet	41	22.5	6.0	19.0	54.3	3.0	1.0
Corn Gluten Meal 60%	92	65.5	20.2	30.6	1.2	8.2	0.0
Fat Animal Veg Blend	99	0.0	0.1	2.8	0.0	2.2	0.0
Fat Hydrol. Tallow	99	0.0	0.0	0.0	0.0	0.0	0.0
Fat Tallow Beef	99	0.0	0.0	0.0	0.0	0.0	0.1
Fat Tallow Porcine	99	0.0	0.0	0.0	0.0	0.0	0.0
Molasses Beet	75	8.5	0.1	0.1	4.0	13.3	0.1
Molasses Cane	73	5.8	9.6	6.8	68.3	4.8	0.3
Molasses Dried	74	5.8	17.3	30.1	24.9	11.9	0.0
Potatoes	23	9.5	47.5	65.9	1.7	5.0	0.0
Rice Bran	91	14.0	47.5	65.9	1.7	5.0	1.0
Soybean Hulls Ground	91	12.1	0.0	0.0	97.8	0.1	1.0
Soybean Hulls Pellet	91	12.1	0.0	0.0	5.0	0.1	0.1
Soybean Meal 44 Solvent	90	49.0	6.3	13.0	3.3	5.6	0.1
Soybean Meal 47.5 Solvent	90	51.5	6.0	13.0	4.4	5.8	3.5
Soybean Whole Raw	90	41.8	38.0	64.0	9.0	3.0	0.0
Soybean Whole Roasted	93	41.7	0.0	0.0	0.0	0.0	0.1
Sugar Confectioners	92	0.0	8.0	25.0	33.2	2.0	0.2
Tomato Mix	24	19.9	41.1	49.2	1.3	7.1	0.0
Wheat Midds	89	18.4	0.0	0.0	0.0	10.5	0.6
Wheat Mill Run	95	15.0	0.0	0.0	0.0	10.0	0.8
Whey Acid	7	14.2	0.0	0.0	0.0	18.0	0.2
Whey Condensed	20	14.6	18.0	43.8	7.5	6.9	0.4
Whey Delactose	93	17.9	23.0	47.1	4.4	4.3	0.3

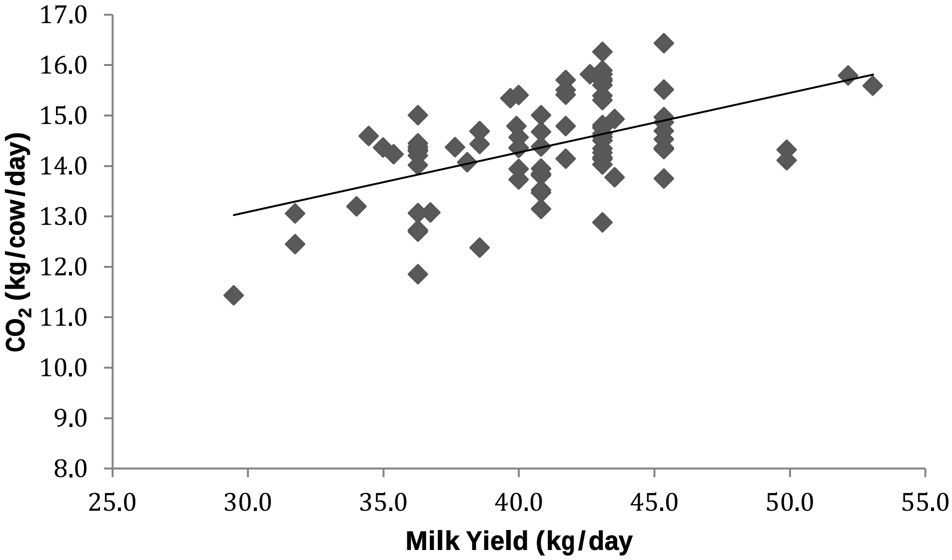

Figure 1. Milk yield versus predicted carbon dioxide emissions (kg/cow/d). The regression equation was CO_2 (kg/d) = 0.12 × milk yield (kg/d) + 9.69 ($R^2 = 0.69$; RMSE = 0.64 kg/d).

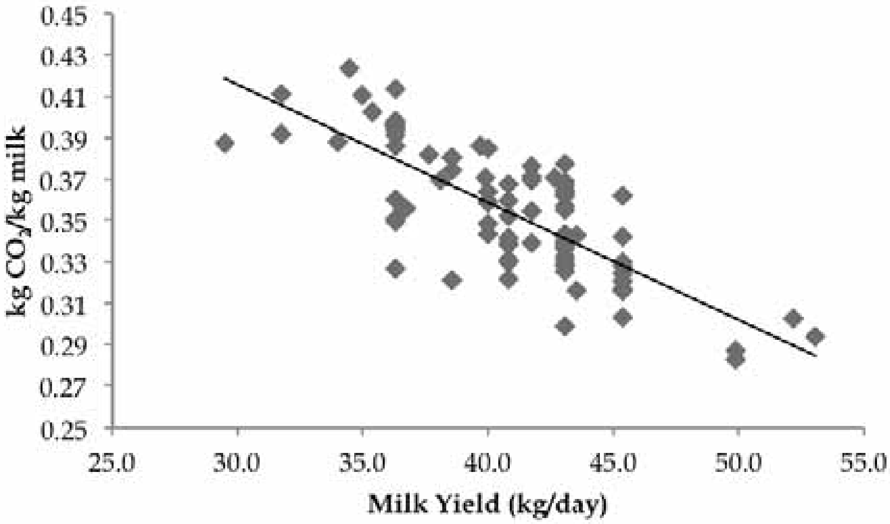

Figure 2. Predicted CO_2 emissions per kg of milk versus milk yield. The regression equation was kg CO_2/Kg milk = -0.006 × milk yield (kg/d) + 0.59 ($R^2 = 0.81$; RMSE = 0.02 kg CO_2/ kg milk.

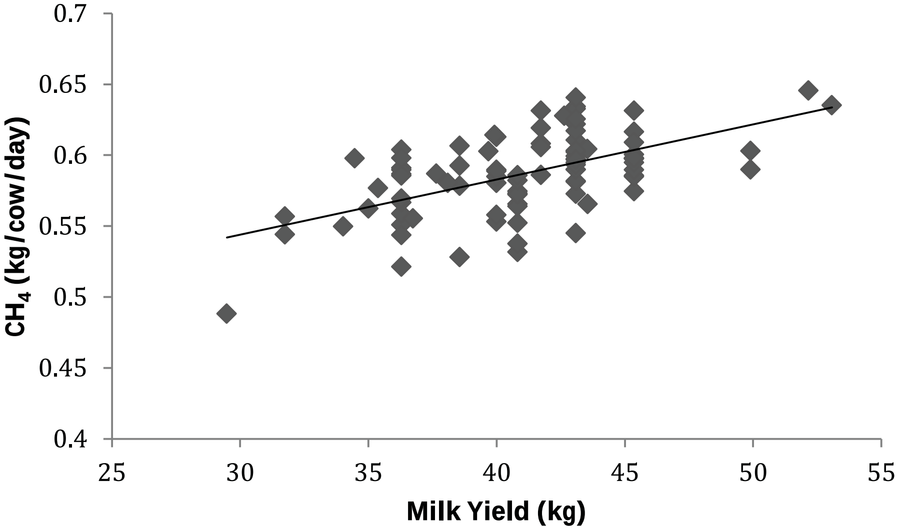

Figure 3. Milk yield versus predicted methane emissions (kg/cow/d). The regression equation was CH_4 (kg/d) = 0.004 × milk yield (kg/d) + 0.43 ($R^2 = 0.75$; RMSE = 0.02 kg/d).

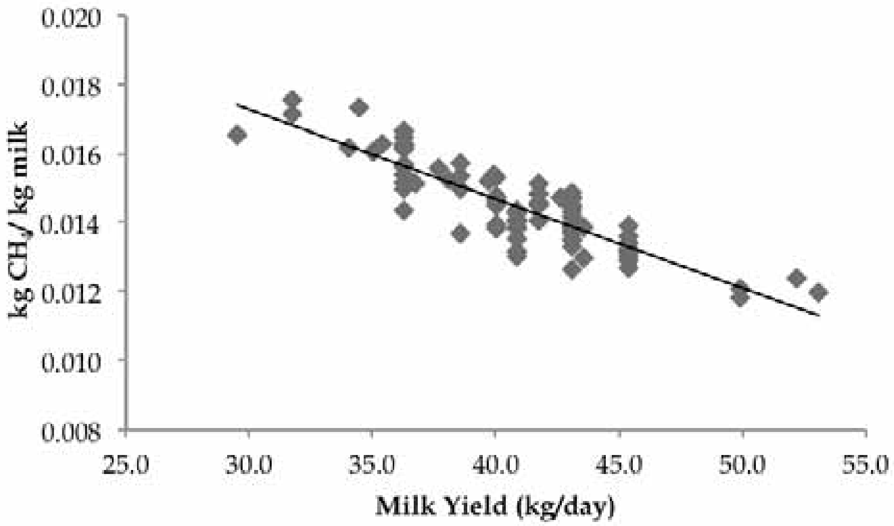

Figure 4. Predicted methane emissions per kg of milk versus milk yield. The regression equation was kg CH_4/Kg milk = -0.0003 × milk yield (kg/d) + 0.03 ($R^2 = 0.89$; RMSE = 0.0005 kg CH_4/ kg milk.

Comparative Emissions from Animals or Combustion

Predictions of carbon dioxide and methane (as CO_2 equivalents) emissions from the animal and CO_2 release in the event of total combustion of the byproducts are in Table 5. The data represent the minimum, mean and maximum byproduct inclusion levels in the dataset. Figure 5 shows the total gas emissions from animals or combustion across the range in the dataset.

Table 5. Comparison of gas released from byproduct disposal between dairy cows and incineration (combustion).

Variable	Dietary byproduct inclusion	CO_2 from byproducts	CH_4 from byproducts	Total gas release[1]	CO_2 combustion
	% ration DM	kg CO_2 Eq./cow/d			kg
Mean	31	4.5	4.6	9.0	46.2
SD	9	1.4	1.4	2.8	4.9
Min	13	1.8	1.9	3.7	25.0
Max	57	7.4	7.9	15.3	54.9

[1] Total gas release = CO_2 (kg/d) + CH_4 (kg CO_2 Eq./d)

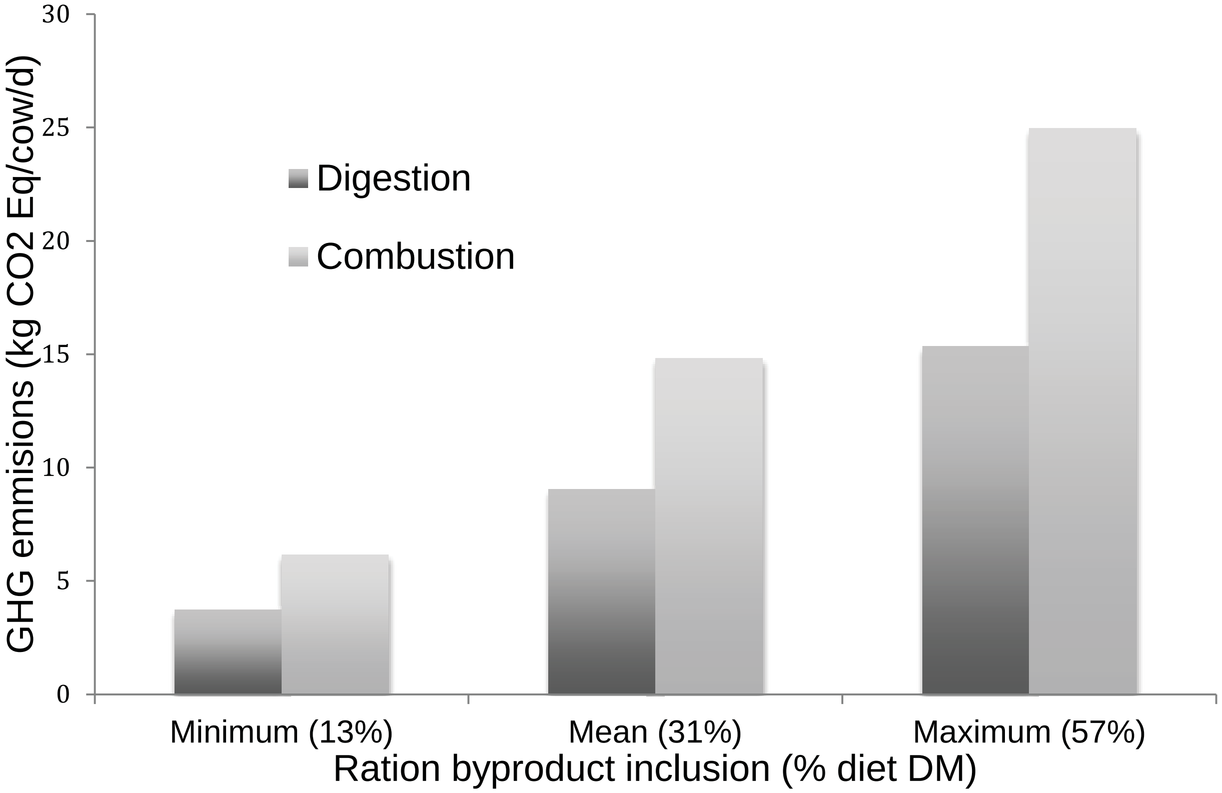

Figure 5. Comparison of carbon dioxide equivalent emissions from byproduct disposal between dairy cows and combustion. Combustion was used for a discrete comparison.

Carbon Equivalents of High Inclusion Byproducts

The top five byproducts that were represented the most in the diets analyzed were corn gluten feed, distiller's grains (corn distillers from ethanol), soybean meal, whole (fuzzy) cottonseed and solvent extracted canola meal, representing 2.08%, 2.63%, 3.45%, 4.23% and 4.24% of the total DM of all diets received, respectively. Results of carbon content calculations and subsequent greenhouse gas release from these byproducts is found in Table 6.

Table 6. Combustion analysis of top 5 byproducts (% DM inclusion)

	Diets containing each byproduct (% dataset)	Average Inclusion (% of diet)	Byproduct DM fed (kg/cow)	C (% DM)	Grams GHG/cow/d (CO_2 Eq.)	Grams CO_2 (equivalent DM combusted) [1]
Corn Gluten Feed	37	8.0	2.0	47	2324	3489
Corn Distiller (Ethanol)	48	5.3	1.3	51	1545	2490
Soybean Meal	63	5.6	1.4	52	1608	2613
Cottonseed Fuzzy (Whole)	69	6.0	1.5	52	1739	2851
Canola Meal	66	8.1	2.0	53	2289	3792

[1] Calculated using %C equation, Adams et al. (1951)

DISCUSSION

The models used to predict carbon dioxide and methane emission as functions of nutrient intake were developed from complete diets and total mixed rations, and the implications of attributing only particular portions of the diet to these models have not yet been explored. Comparing the two extant equations Kirchgessner et al., 1991 and Casper and Mertens, (2010) demonstrates remarkable similarity between the two and indicates that either equation could be successfully adopted for this application. The predicted values were consistent with measured data reported by Casper and Mertens (2010) and Liu et al., (2012). However, lower (~ 4,000g CO_2/d) than other reports (Aguerre et al., 2011, Sejian et al., 2011) indicting some variation among the experimental methods used to conduct the emissions measurements or predict them. It should also be noted that the equations use daily milk yield and body weight as the primary variables to predict carbon dioxide emission, thus any unaccounted for variation in milk yield or body weight will provide biased predictions and although body weight is a standard input in many models it is rarely truly measured on dairy farms.

Comparison of the methane prediction with the data from Aguerre et al. (2011) and Liu et al. (2012) demonstrates that the methane prediction equation (Mills et al., 2003), as implemented in the CNCPS provides high accuracy and precision. The measured methane emissions from Liu et al. (2012) ranged from 16 to 22 g/kg DMI and from 9 to 14 g/kg milk, consistent with the predictions from the CNCPS evaluation. Thus, this allows field level nutritionists the ability to evaluate methane emissions as they formulate diets and also allows other decision makers the ability to evaluated extant diets for methane emissions and to model diets to understand how to reduce methane emissions per unit of milk.

The data presented in Figure 1 and Figure 3 reinforces the accepted relationship between milk yield and gas emissions. As milk yield and DMI increase, carbon dioxide production increases since it represents the increase in metabolism to produce the increased milk. However, more important is the dilution of maintenance effect observed in Figures 2 and 4 that is most relevant to the industry. This has been well described by Capper et al., 2008a,b; 2009) and reinforced by more recent actual farm level measurements (Liu et al, 2012).

It has been suggested that the industry should not consider carbon dioxide emissions and only focus on methane and nitrous oxide because the assumption is made that all carbon from carbon dioxide excreted by the cow originates from plants and returns to them at the end of the process, thus making the cycle neutral (IPCC, 2007). We recognize that consideration and also recognize that the components of the diet associated with the carbon dioxide and equivalents emissions have not been fully described, thus without understanding the sources of CO_2 production, policy and decision makers might focus reduction efforts in areas that are not sustainable or useful.

Accounting for all carbon in the byproducts and observing the difference in value between incineration CO_2 and respiration CO_2, it is clear that upon digestion, some carbon is lost to other sinks. This loss accounts for the lesser amount of carbon dioxide that is released as a greenhouse gas when the byproducts were used as dairy feedstuffs. With consideration of these differences the representation of carbon dioxide emission in Figure 5 is limited in the sense that it only addresses carbon released into the atmosphere and does not account for other sinks (milk, tissue, feces and urine).

Although this is not news to the dairy industry, the analyses demonstrate that by incorporating byproducts into dairy cattle diets, the industry is doing a service to society and the environment by recycling carbon into milk that would otherwise be combusted, or dumped into landfills. After the utilization of this element for tissue requirements of the animals, milk production and fecal excretion, the amount of CO_2 excreted is more than 5 fold less than the levels that would be emitted if the same amount of carbon was combusted (Figure 5).

Although methane is considered more potent than carbon dioxide and should therefore be limited in release, once expressed as carbon dioxide equivalents and added to the carbon dioxide released by cattle, the total greenhouse gas emission is still less than amounts that would be released if byproducts were combusted. In this sense, the dairy industry is indispensable to the environment and should be credited for ecologically managing waste products from industries that produce byproducts of food for direct human consumption.

This study suggests there is a crucial ecological aspect that needs to be considered when evaluating the role of animal based food production in the U.S. A greater understanding is necessary to appreciate the role the dairy industry plays in utilization of byproducts of the human food system to provide milk and dairy products and also of the industry’s contribution to ecological recycling through the use of byproducts.

CONCLUSION

There is a significant benefit of byproduct use as feed for dairy cattle from an environmental standpoint. Feeding byproducts reduces the likelihood that industries will dispose of unavoidable waste products in less environmentally friendly ways. In comparison to disposal by combustion, rumen digestion of byproduct carbon emits significantly less greenhouse gases and recycles carbon into milk for human consumption and manure that is reused in other ways. Use of byproducts in diets for dairy cattle reduces the environmental impact of human food production and enhances the efficiency of the industry by making use of feed components that do not compete with the human food chain and compliment it.

Acknowledgements

This paper was edited from an Honor’s Thesis by Kristen Russomanno (Cornell University, 2012). We are grateful to the nutritionists and industry professionals from around the country that so graciously and anonymously provided diets for use in this analysis. Thank you for your contribution.

REFERENCES

Adams, R. C., M. F. S., J. K. Dixon, F. M. Bennett, G. I. Martin, and R. C. Lough. 1951. The utilization of organic wastes in N.Z.: Second interim report of the interdepartmental committee. Pages 396-424 in New Zealand engineering. Wellington, N.Z.

Aguerre, M. J., M. A. Wattiaux, J. M. Powell, G. A. Broderick, and C. Arndt. 2011. Effect of forage-to-concentrate ratio in dairy cow diets on emission of methane, carbon dioxide, and ammonia, lactation performance, and manure excretion. J. Dairy Sci. 94:3081-3093.

Aguilar, A. A., N. E. Smith, and R. L. Baldwin. 1984. Nutritional value of almond hulls for dairy cows. J. Dairy Sci. 67:97-103.

Bampidis, V. A. and P. H. Robinson. 2006. Citrus by-products as ruminant feeds: A review. Animal Feed Science and Technology 128:175-217.

Capper, J. L., R. A. Cady, and D. E. Bauman. 2008a. Increased production reduces the dairy industry’s environmental impact. Pgs 55-66 in Proc. Cornell Nutr. Conf., Syracuse, NY.

Capper, J. L., R. A. Cady, and D. E. Bauman. 2009. The environmental impact of dairy production: 1944 compared with 2007. J. of Animal Sci. 87:2160-2167.

Capper, J. L., E. Castaneda-Gutierrez, R. A. Cady, and D. E. Bauman. 2008b. The environmental impact of recombinant bovine somatotropin (rbst) use in dairy production. Proceedings of the National Academy of Sciences 105:9668-9673.

Casper, D. P. and D. R. Mertens. 2010. Carbon dioxide, a greenhouse gas sequestered by dairy cattle. J. of Dairy Sci. 93(E-Supp. 1):843-844.

Chianese, D. S., C. A. Rotz, and T. L. Richard. 2009. Simulation of carbon dioxide emissions from dairy farms to assess greenhouse gas reduction strategies. Transactions of the ASABE 52:1301-1312.

EPA. 2010. Questions and answers: The methane to markets partnership. Environmental Protection Agency (EPA), Washington, DC.

Fox, D. G., L. O. Tedeschi, T. P. Tylutki, J. B. Russell, M. E. Van Amburgh, L. E. Chase, A. N. Pell, and T. R. Overton. 2004. The cornell net carbohydrate and protein system model for evaluating herd nutrition and nutrient excretion. Animal Feed Science and Technology 112:29-78.

Higgs, R. J., L. E. Chase, D. A. Ross, and M. E. Van Amburgh. 2012. Evaluating and refining the cncps feed library using commercial laboratory feed databases. in Proc. Cornell Nutr. Conf., Syracuse, NY.

IPCC. 2007. Climate change 2007: Th e physical science basis. In: S. Solomon et.al., editors, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. p. 94–127.

Kirchgessner, M., W. Windisch, H. L. Muller, and M. Kreuzer. 1991. Release of methane and of carbon dioxide by dairy cattle. Agribiol. *Res.* 44: 91-102.

Liu, Z., W. Powers, B. Oldick, J. Davidson, and D. Meyer. 2012. Gas emissions from dairy cows fed typical diets of Midwest, South, and West regions of the United States. J. Environ. Qual. 41:1228-1237.

Mills, J. A. N., E. Kebreab, C. M. Yates, L. A. Crompton, S. B. Cammell, M. S. Dhanoa, R. E. Agnew, and J. France. 2003. Alternative approaches to predicting methane emissions from dairy cows. J. of Animal Sci 81:3141-3150.

Mowrey, A. and J. N. Spain. 1999. Results of a nationwide survey to determine feedstuffs fed to lactating dairy cows. J. of Dairy Sci. 82:445-451.

SAS. 2010. Jmp. SAS Institute Inc., Cary, NC, USA.

Sejian, V., C. Alan Rotz, J. Lakritz, T. Ezeji, and R. Lal. 2011. Modeling of greenhouse gas emissions in dairy farms. J. of Animal Sci. Advances 1:12-20.

St-Pierre, N. R. 2001. Invited review: Integrating quantitative findings from multiple studies using mixed model methodology. J. Dairy Sci 84:741-755.

Tylutki, T. P., D. G. Fox, V. M. Durbal, L. O. Tedeschi, J. B. Russell, M. E. Van Amburgh, T. R. Overton, L. E. Chase, and A. N. Pell. 2008. Cornell net carbohydrate and protein system: A model for precision feeding of dairy cattle. Animal Feed Sci and Tech 143:174-202.

UN. 2005. World population prospects: The 2005 revision. United Nations Population Division of the Department of Economic and Social Affairs. Retreived from: http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf.

USDA. 2003. Situation and outlook for citrus. Horticultural and tropical products division, united states department of agriculture (usda). Retreived from: http://www.fas.usda.gov/htp/Hort_Circular/2002/02-08/Citrus%20FEA.htm

Van Amburgh, M. E., L. E. Chase, T. R. Overton, D. A. Ross, E. B. Recktenwald, R. J. Higgs, and T. P. Tylutki. 2010. Updates to the cornell net carbohydrate and protein system v6.1 and implications for ration formulation. Pg. 144-159 in Proc. Cornell Nutr. Conf., Syracuse NY.