CHARACTERIZE CALIFORNIA-SPECIFIC CATTLE FEED RATIONS AND IMPROVE MODELING OF ENTERIC FERMENTATION FOR CALIFORNIA'S GHG INVENTORY

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Animal subjects: not used

Human subjects: not used

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1. ABSTRACT

The amount of methane (CH_4) produced from enteric fermentation depends primarily on feed intake and diet composition. The diet formulated by California's cattle industry has been changing depending on feed availability and cost. Milk production has increased linearly over the last 6 decades with a concomitant increase in feed or dry matter intake (DMI). Methane emissions are expected to decrease per unit of milk produced as feed efficiency increases. It is not possible to measure enteric CH_4 production from all animals in the state, therefore, mathematical models are widely used to estimate emissions. However, empirical models developed on low producing cattle or different feed regimen might not be robust enough to use in California. The objectives of this study are (1) to improve the modeling methodology for estimating cattle enteric CH_4 emissions in the California Greenhouse Gas Emission Inventory by developing mathematical models, (2) evaluate new and extant emission estimation models and (3) collect data on California-specific cattle diets and improve enteric CH_4 emissions from the state. The proposed study will involve three major tasks. The first task will be developing a set of equations for predicting enteric CH_4 emissions from cattle using DMI and composition data applicable to California cattle systems. The second task will be evaluating the CH_4 emission estimates from newly developed models and the estimates from the methodologies used by US EPA. Both of these tasks require measured data on CH_4 emission, DMI and diet composition. Because CH_4 emission measurements are not available in commercial farms, data applicable to California and experiments conducted at UC Davis, particularly in Dr Kebreab's lab will be used. More data will be collated from a literature review. We expect new models developed on California-specific data to perform better than the US EPA methodologies developed on national databases. The third task will be collecting feed ingredients, DMI and diet composition of cattle farms in California and applying the models to estimate regional and statewide CH_4 emissions from enteric fermentation. The improved emission estimates for the GHG Emission Inventory will better reflect on-farm realities, improve understanding of regional emissions, and inform the development of short-lived climate pollutant reduction strategies. The study will be carried out by well qualified scientists having extensive prior-experiences on similar tasks. The study goals will be accomplished within one year and anticipate the results to be published in a peer-reviewed journal.

2. INTRODUCTION

Enteric emissions comprise the largest known source of methane (CH_4) in California, constituting about 30% of GHG inventory in California. According to ARB, 96% of total enteric CH_4 in California was generated from cattle, 73% of which was from dairy cattle in 2012 (ARB, 2014). Although the national dairy cattle populations have generally been decreasing since 1990, some states including California have seen increases in their dairy cattle populations. USDA's National Agricultural Statistics Service estimates there are approximately 1.8 million dairy cows, which is the highest in the nation and 0.6 million beef cows in California (USDA-NASS, 2012). California dairy cattle alone contribute to 23% of total enteric CH_4 emissions from dairy cattle in the US (EPA, 2014).

The microbial fermentation process in digestive tract, referred to as enteric fermentation, produces CH_4 as a byproduct, which can be exhaled or eructated by the animal. The amount of CH_4 produced and emitted by an individual animal depends primarily on the amount and type of feed it consumes. Although emissions from few animals under controlled conditions can be measured, it is not practical to do so from millions of ruminant animals. Therefore, estimates rely on mathematical models developed to predict emissions based on various factors. However, the extant mathematical models have been developed on wide variety of DMI and diet composition data. Therefore, as Hippenstiel et al. (2013) showed, many models appear to fail when challenged on data related to specific regional origin and diet composition. One feasible strategy for addressing this issue is to develop production level-specific models as different production levels are related to different regions and diet compositions. This strategy can particularly be justified to California dairy herds because the majority of California dairy diets have been formulated to meet milk production goals (Robinson, 1999).

The dairy industry in California has been expanding in the last few decades. In addition, the milk production levels of the cows have increased linearly (von Keyserlingk et al., 2013). Based on milk production data in 2013, the average milk yield ranged from 23 to 36 kg/cow/d across major dairy producing counties in California with a mean production of 31 kg/cow/d. This is 15% greater than the national average, which is 27 kg/cow/d (USDA-NASS, 2012). Given the strong positive relationship between milk yield and dry matter intake (DMI, kg/cow/d), which is then positively associated with enteric CH_4 production, an average California dairy cows potentially emits more

CH_4 than average US dairy cow but less if calculated per unit of product basis. Therefore, mathematical models developed on national databases may not be accurate when used to estimate enteric CH_4 emissions from California cows. Moreover, the present day rations for California dairy cows appear to be more reliant on slowly fermenting structural carbohydrates and less reliant on rapidly fermenting carbohydrates such as starch (Robinson, 2003). These dietary changes will have an impact on enteric methane emissions estimates. There has been disagreements between methane emission estimates from livestock based on high-resolution atmospheric transport model (Miller et al., 2013) and US EPA calculations, which was challenged by Hristov et al. (2014). Models developed on California-specific DMI and diet nutrient composition data should be more appropriate to use for predicting enteric CH_4 emissions from California cattle. Such models will improve the accuracy of our CH_4 inventory estimates.

3. OBJECTIVES

The overall objective of this study is to improve the modeling methodology for estimating cattle enteric CH_4 emissions in the California Greenhouse Gas Emission Inventory by collecting data applicable to California cattle diets and thereby developing California-specific prediction models and enteric methane estimates. The following specific objectives will be accomplished during the study.

1. To develop California-specific enteric methane prediction models using data applicable to California cattle systems.
2. To evaluate the models by challenging them with data from applicable research in the literature and from experiments conducted at UC Davis.
3. To collect data on rations, DMI and nutrient composition from various regions of the state and apply the models to obtain improved estimates of enteric CH_4 emissions.

The improved emission estimates for the GHG Emission Inventory will better reflect on-farm realities, improve understanding of regional emissions, and inform the development of short-lived climate pollutant reduction strategies.

4. TECHNICAL PLAN

Data Sources. This research will not use test specimens, animals, or human subjects. The major input to this project will be data on enteric methane emission measurements, DMI, and dietary nutrient composition and corresponding diet, production, and animal characteristics. The Kebreab laboratory at UC Davis has an extensive database containing over 1,000 individual measurements of lactating and dry cows. Moreover, the database includes more than 1,000 measurements of heifers and beef steers (Moraes et al. 2014). Those data were from 62 indirect respiration calorimetry experiments conducted in the former USDA Energy Metabolism Unit (EMU) at Beltsville, MD. Besides enteric methane emission measurements (g/cow/d), the EMU database include detailed descriptions of dietary composition along with DMI, milk yield and milk composition. The Kebreab laboratory also have a separate database comprising more than 40 individual lactating dairy cow measurements from experiments conducted at UC Davis with additional 40 measurements to be collected before July, 2015. Prof Mitloehner's group also have some data on enteric emissions and these will be included in the database. A literature review of related studies will also be conducted and treatment means added to the database. Additionally, data representing primarily DMI and nutrient composition of commercial cattle diets in California will be collected. One valuables source is Dr. Peter Robinson in the Department of Animal Science at UC, Davis. Dr. Robinson has collected information on recent dairy ration changes in several regions of California. Moreover, we will collaborate with Agriculture and Natural Resource Division to collect data on feed intake and feed ingredients used in cattle diets. The NRC (2001) tables will be then used to calculate dietary nutrient composition of those diets if proximate analysis were not conducted. Furthermore, cattle population and herd composition data of different regions of California will be obtained from California Department of Food and Agriculture (CDFA) Statistics (CDFA, 2013).

Model Development. The primary focus will be placed on developing a model for predicting enteric methane emissions from lactating dairy cows, which contribute to the majority of CH_4 emissions from livestock in California. For this purpose, only the data corresponding to milk production level (average yield = 31 kg/cow/d) of California cows will be chosen from the EMU database. We expect to have more than 500 observations in this subset of data. Separate CH_4 prediction models will be also developed for non-lactating cows, dairy heifers and beef cattle using respective data in the EMU database. Dietary nutrient composition and DMI will serve as primary variables driving CH_4 production. Dietary nutrient composition variables that are not available in commercial farms will not be used as potential predictor variables to the models. Variables to be included in the models and the best prediction model within each cattle group will be selected taking both prediction accuracy and model simplicity into consideration as described in two previous articles by the Kebreab lab (Appuhamy et al., 2014; Moraes et al., 2014). The model will be developed using the statistical software R, which has been extensively used by the group in several of their recent mathematical modeling work (e.g., Appuhamy et al., 2014 and Moraes et al., 2014).

Model Evaluation. Each model developed will be separately challenged on the cattle experiment data available at UC Davis and the literature data. We will evaluate the models primarily for both prediction accuracy and precision. Accuracy reflects how close the predicted values to the measured values, whereas precision reflects whether predicted values follow the same variability pattern as observed values. Moreover, model efficiency indicating worth of using model estimates over just using the average measured value will also be assessed. Several model evaluation statistics such as mean square prediction error and its components, concordance correlation coefficient, index of agreement, and Nash-Sutcliffe efficiency will be used to assess accuracy, precision, and model efficiency (Kebreab et al., 2008; Moriasi et al., 2007). Along with the newly developed models, the IPCC Tier 2 model modified by EPA will be also evaluated on the same data.

Estimating California emissions. The developed models will be applied on DMI and dietary nutrient composition data on different regions of California to estimate corresponding enteric CH_4 emissions from individual animals in each cattle group. Region-specific herd composition and cattle population data will be then used to estimate regional and statewide emissions

We expect the deliverables from this project to be (1) quarterly progress reports (2) methodology for estimating methane emissions from California (3) representative dietary regiment from various regions and types of cattle (4) emission estimates from the state (5) peer-reviewed publication(s), as appropriate and (6) final report and research seminar in Sacramento, CA.

5. REFERENCES

Similar work done by the applicants

1. Appuhamy, J. A. D. R. N., Moraes, L. E., Wagner-Riddle, C., Casper, D. P., France, J. and Kebreab, E. 2014. Development of mathematical models to predict volume and nutrient composition of fresh manure from lactating Holstein cows. Animal Production Science 54:1927-1938.
2. Hristov, A. N., K. A. Johnson, and E. Kebreab. 2014. Livestock methane emissions in the United States. Proceedings of the National Academy of Sciences of the United States of America 111(14):E1320-E1320.
3. Moraes, L. E., Strathe, A. B., Fadel, J. G., Casper, D. P. and Kebreab, E. 2014. Prediction of enteric methane emissions from cattle. Global Change Biology 20:2140-2148.
4. Kebreab, E., Johnson, K. A., Archibeque, S. L., Pape, D. and Wirth, T. 2008. Model for estimating enteric methane emissions from United States dairy and feedlot cattle. Journal of Animal Science 86:2738-48.
5. von Keyserlingk, M.A.G., N. P. Martin, E. Kebreab, K. F. Knowlton, R. J. Grant, M. Stephenson, C. J. Sniffen, J. P. Harner, III, A. D. Wright, and S. I. Smith. 2013. Invited Review: Sustainability of the U.S. dairy industry. Journal of Dairy Science 96:5405-5425.

Other

1. ARB. 2014. Air Resource Board-California Greenhouse Gas Inventory for 2000-2012 — by IPCC Category. http://wwwarbcagov/cc/inventory/data/tables/ghg_inventory_by_ipcc_00-12_all_2014-03-24pdf.
2. CDFA. 2013. California Cattle Inventory by Class and County. http://wwwcdfacagov/statistics/.
3. EPA. 2014. US GHG Inventory 2014 (Chapter-6). http://wwwepagov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-6-Agriculturepdf.
4. Hippenstiel, F., Pries, M., Buscher, W. and Sudekum, K. H. 2013. Comparative evaluation of equations predicting methane production of dairy cattle from feed characteristics. Archives of Animal Nutrition 67:279-88.
5. Miller, S. M., Wofsy, S. C., Michalak, A. M., Kort, E. A., Andrews, A. E., Biraud, S. C., Dlugokencky, E. J., Eluszkiewicz, J., Fischer, M. L., Janssens-Maenhout, G. and others. 2013. Anthropogenic emissions of methane in the United States. Proceedings of the National Academy of Sciences 110:20018-20022.
6. Moriasi, D. N., Arnold, J. G., Van Liew, R. L., Bingner, R. D., Harmel, R. D. and Veith, T. L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50:885-900.
7. NRC. 2001. Nutrient requirements of dairy cattle. 7th revised edition. National Academy of Science, Washington, DC.

8. NASS-USDA. 2012. California Livestock Review. http://wwwnassusdagov/Statistics_by_State/California/Publications/Livestock/201202lvsrvpdf.
9. Robinson, P. H. 1999. Evaluating commercial California dairy rations 1. ration, behavior, rumen pH, and milk production. http://animalscienceucdavisedu/faculty/robinson/Articles/FullText/PDF/web199906PDF.
10. Robinson, P. H. 2003. Estimating the Energy Value of Dairy Feeds: Evaluating UC DAVIS and NRC (2001) Equations, Coorporative Extention University of California, Davis. http://animalscienceucdavisedu/faculty/robinson/Articles/FullText/PDF/Web200303pdf.

6. PROJECT SCHEDULER

Task 1: Retrieving data representative of California cattle systems from the database and model development

Task 2: Literature search for methane emission data and retrieving relevant data from UC Davis cattle experiment database

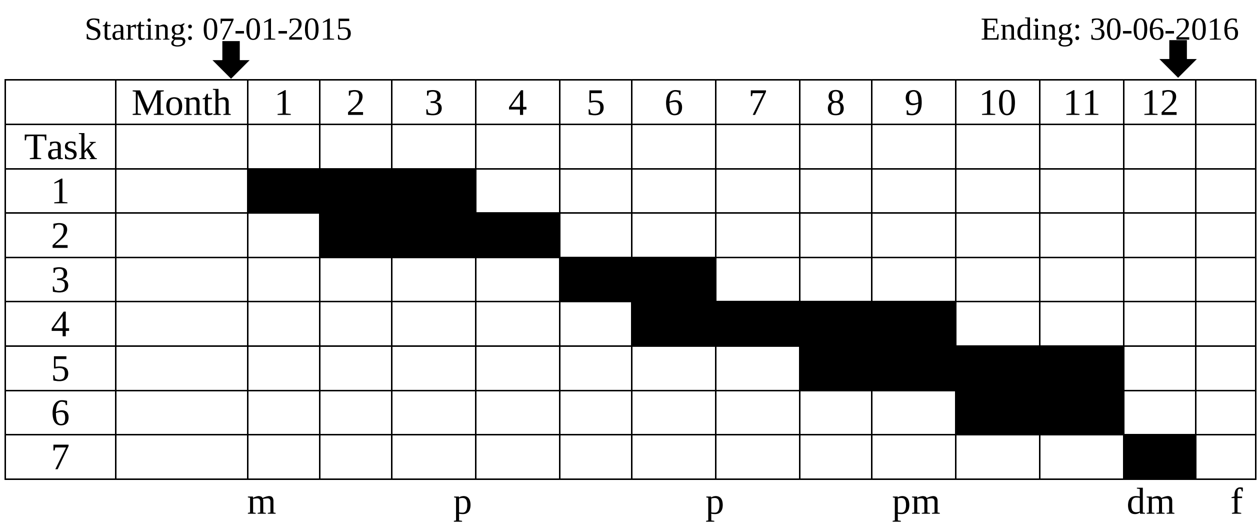
Task 3: Evaluation of the models on the experimental data and the literature data

Task 4: Collecting data on feed intake, diet composition of commercial cattle farms, cattle population and herd composition

Task 5: Applying the models to estimate enteric CH_4 emissions from California cattle

Task 6: Draft final report

Task 7: Amend final report and manuscript preparation



p = progress report

m = meeting with ARB staff

d = deliver draft final report

f = deliver final report

7. CURRICULUM VITAE OF KEY SCIENTISTS

Ermias Kebreab
Professor of Animal Science, Sesnon Endowed Chair in Sustainable Agriculture
Deputy Director, Agricultural Sustainability Institute
Department of Animal Science, University of California, Davis

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EDUCATION

University	Degree	Year	Major
University of Reading (United Kingdom)	Ph.D.	1998	Integrated Biology
University of Reading (United Kingdom)	M.Sc.	1991	Integrated Biology
University of Asmara (Eritrea)	B.Sc.	1987	Biology/Mathematics

POSITION AND EMPLOYMENT HISTORY

2009 -	Professor, Sesnon Endowed Chair. Department of Animal Science, University of California, Davis, CA.
2007-2009	Associate Professor, Canada Research Chair. Department of Animal Science, University of Manitoba, Winnipeg, MB.
2003-2006	Adjunct Professor. Centre for Nutrition Modeling, Department of Animal and Poultry Science, University of Guelph, Guelph, ON.
1998-2003	Post Doctoral Research Fellow. School of Agriculture, University of Reading, UK.
1992-1994	Department Head. Department of Plant and Animal Sciences, University of Asmara, Eritrea.
1987-1989	Lecturer. Department of Arid Zone Agriculture, University of Asmara, Eritrea.

HONORS

2014	American Feed Industry Ruminant Nutrition Award, American Society of Animal Science
2010	Technical Innovation in Enhancing Production of Safe Affordable Food Award, Canadian Society of Animal Science
2010	Sesnon Endowed Chair, University of California, Davis
2009	Merit Award in Research, University of Manitoba, Canada
2008	Early Career Achievement Award, American Society of Animal Science
2006	Young Scientist Award, Canadian Society of Animal Science
2005	Senior Research Fellowship, Wageningen University, The Netherlands
1997	Graduate Fellowship, Society for Protection of Science & Learning, UK
1996	Graduate Student Award, Africa Educational Trust, UK

GRANTS AWARDED (last 3 years)

USDA – ‘Enhancing environmental sustainability of dairying in the US.’	200,000
USDA – CIG, ‘Bovine innovative GHG emission reduction strategies in U.S.’	1,100,000

Agricultural Greenhouse Gas Program, ‘Farm-scale assessment of greenhouse gases mitigation strategies in dairy livestock-cropping-systems.’	2,827,000
USAID, ‘Feed the future innovation lab for genomics to improve poultry.’	6,000,000
National Pork Board, ‘Developing a process-based model for estimating air emissions from swine operations.’	980,000
Water Resources Advisory Committee, ‘Energy partitioning in prepubertal Sturgeon.’	750,000
California Fish and Game, ‘Ecological performance of fishes in an ever-changing Estuary: The effects of nutritional status on environmental stress tolerance in Sturgeon.’	420,000
Ajinomoto Heartland, ‘Nitrogen cycling in ruminant livestock systems: a modeling approach.’	42,000
USDA - Foreign Agricultural Service, ‘Ration formulation software for sustainable beef production in Vietnam.’	30,000

RELEVANT PUBLICATIONS (2013-2014)

1. Moraes, L.E., A. B Strathe, J. G Fadel, D. P Casper, and **E. Kebreab.** 2014. Prediction of enteric methane emissions from cattle. Global Change Biol., 20:2140–2148.
2. Hristov, A. N., K. A. Johnson, and **E. Kebreab**. 2014. Livestock methane emissions in the United States. Proceedings of the National Academy of Sciences of the United States of America 111:E1320-E1320.
3. Ellis, J. L., J. Dijkstra, A. Bannink, **E. Kebreab**, S. Archibeque, C. Benchaar, K. A. Beauchemin, J. D. Nkrumah and J. France. 2014. Improving the prediction of methane production and representation of rumen fermentation for finishing beef cattle within a mechanistic model. Can. J. Anim. Sci. 94: 509-524.
4. Appuhamy, J.A.D.R.N., L.E. Moraes, C. Wagner-Riddle, D.P. Casper J. France, and **E. Kebreab**. 2014. Development of mathematical models to predict volume and nutrient composition of fresh manure from lactating Holstein cows. Anim. Prod. Sci. 54:1927-1938.
5. Rendón-Huerta, J.A., J. M. Pinos-Rodríguez, J. C. García-López, L. G. Yáñez-Estrada and **E. Kebreab**. 2014. Trends of greenhouse gas emissions by dairy cattle in México between 1970 and 2010. Anim. Prod. Sci. 54: 292-298.
6. Hristov, A.N., J. Oh, J. L. Firkins, J. Dijkstra, **E. Kebreab**, G. Waghorn, H. P. S. Makkar, A. T. Adesogan, W. Yang, C. Lee, P. J. Gerber, B. Henderson, and J. M. Tricarico. 2013. Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J. Anim. Sci. 91, 5045–5069.
7. Hristov, A.N., T. Ott, J. Tricarico, A. Rotz, G. Waghorn, A. Adesogan, J. Dijkstra, F. Montes, J. Oh, **E. Kebreab**, S.J. Oosting, P. J. Gerber, B. Henderson, H. P. S. Makkar and J. L. Firkins. 2013. Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. J. Anim. Sci. 91, 5095–5113.
8. von Keyserlingk, M.A.G., N. P. Martin, **E. Kebreab**, K. F. Knowlton, R. J. Grant, M. Stephenson, C. J. Sniffen, J. P. Harner, III, A. D. Wright, and S. I. Smith. 2013. Invited Review: Sustainability of the U.S. dairy industry. J. Dairy Sci. 96:5405-5425.
9. Gerber, P. J., A. N. Hristov, B. Henderson, H. Makkar, J. Oh, C. Lee, R. Meinen, F. Montes, T. Ott, J. Firkins, A. Rotz, C. Dell, A. T. Adesogan, W. Z. Yang, J. M. Tricarico, **E. Kebreab**, G. Waghorn, J. Dijkstra and S. Oosting. 2013. Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review. Animal, 7:s2, 220–234.

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Educational Qualifications

Ph.D.	**Animal Science……………………………………………….(2010)**
	Department of Dairy Science, College of Agriculture and Life Sciences, Virginia Tech, Blacksburg, VA, USA
M.Sc.	**Dairy Science………………………………………...(2006)**
	Department of Dairy Science, College of Agriculture and Life Sciences, Virginia Tech, Blacksburg, VA, USA
B.Sc.	**Agriculture…………………….....………………..(2000)**
	Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

Research Experiences

Post-doctoral Associate…………………………………………………2012-continue

Department of Animal Science, University of California, Davis, CA, USA

- Mathematical modeling for determining greenhouse gas emissions and nutrient excretions in fresh manure from lactating dairy cows
- Investigating the effects of environmental temperature, and dietary nitrogen and mineral intake on body water kinetics of lactating dairy cows

Post-doctoral Associate…………………………………………………2010-2011

Department of Animal and Poultry Sciences, University of Guelph, Guelph, ON, Canada

- Mathematical modeling on type 2 diabetes prevalence and incidence with respect to associations between lifestyle interventions and diabetes biomarkers

Publications

- **Appuhamy, J. A. D. R. N**., L. E. Moraes, C. Wagner-Riddle, D. P. Casper, J. France, E. Kebreab. **2014**. Development of mathematical models for determining volume and nutrient composition of fresh manure from Lactating Holstein Dairy Cows. Anim. Prod. Sci. 54:1927-1938
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- **Appuhamy, J. A. D. R. N.**, A. B. Strathe, S. Jayasundara, C. Wagner-Riddle, J. Dijkstra, J. France, E. Kebreab. **2013**. Anti-methanogenic effects of monensin in dairy and beef cattle: a meta-analysis. J. Dairy Sci. 96(8):5161-73
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- Hanigan, M. D., **J. A. D. R. N. Appuhamy**, and P. Gregorini. **2013**. Revised digestive parameter estimates for the Molly cow model. J. Dairy Sci. 96(6):3867-85
- **Appuhamy, J. A. D. R. N**., J. R. Knapp, O. Becvar, J. Escobar, M. D. Hanigan. **2011**. Effects of jugular-infused lysine, methionine, and branched-chain amino acids on milk protein synthesis in high producing dairy cows. J. Dairy Sci. 94(4):1952-60.
- **Appuhamy, J.A.D.R.N.**, B.G. Cassell, and J.B. Cole. **2009**. Phenotypic and genetic relationships between common health disorders and milk and fat yield persistencies from producer recorded health data and test day yields. J. Dairy Sci. 92: 1785-95

Peer Reviewer

Journal of Dairy Research……………………………………………… (2010)

Journal of Dairy Science ……………………………………………… (2014)

CAB Reviews…………. ……………………………………………… (2014)

8. **ESTIMATED COST BY TASK**

Task	Labor	Employee Fringe Benefits	Materials and Supplies	Overhead	Total
1	$12,512	$2,286		$1,480	$16,278
2	$12,512	$2,286		$1,480	$16,278
3	$6,256	$1,143		$740	$8,139
4	$18,768	$3,430		$2,220	$24,418
5	$12,512	$2,286		$1,480	$16,278
6	$6,256	$1,143		$740	$8,139
7	$6,256	$1,143	$2,100	$950	$10,139
	$75,072	**$13,717**	**$2,100**	**$9,090**	**$99,979**