Agriculture, Food, and Climate Change: Assessment of the Research on Greenhouse Gas Emissions (GGEs) from Food Systems and Recommendations for GGE Reductions in Campus Dining Services

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Contents of Report

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Introduction

Agrifood system related activities account for 30 to 50 percent of global anthropogenic greenhouse gas emissions (GGEs), therefore improvements to the agrifood system, may have significant implications for reductions in GGEs and reversing negative trends toward global climate change. The purpose of the following literature review and policy recommendations is to assist University students, staff, and faculty in making dietary and procurement decisions that have the smallest ***climate foodprint***, or least GGEs associated with production, processing, distribution, consumption, and post-consumption.

The literature review is based on evidence from the most current and supported scientific research findings, particularly from published scholarly articles, and provides a critical summary of the research that has been conducted to date measuring the GGEs of different foods, particularly foods that together comprise recommended daily allowances as outlined by the United States Department of Agriculture.

In conducting this literature review, we identified the most significant and relevant research for the purpose of our project with the primary goals of (1) analyzing the theory and data linking diet and climate change, (2) analyzing the methods used to estimate the contribution of diets to climate, and (3) identifying how the theory, data, and methods may be used to inform policies for campus dining. Another objective of the literature review was to consider gap areas within the research linking diet to climate change.

We suggest that future research should expand on findings from the literature to include interviews with experts working within the field of food, agriculture, and climate change. Although not included in this literature review, seafood, pork and beverages also need to be examined for best practices in terms of reducing GGEs from campus dining services.

Results of the literature review, including policy recommendations, do not necessarily reflect the beliefs, values, or attitudes of the University of California or the National Real Food Challenge. Furthermore, it is not the intent of the authors to prioritize reductions in GGEs over other certifications accounted for by the existing Real Food Calculator, published by the Real Food Challenge, but rather to encourage that goals for reductions in GGEs be used in complement with these criteria:

- Fair-trade
- Local
- Humane
- Organic and/or ecologically sound

Executive Summary

Since the 18th century, human activity has increased the concentration of carbon dioxide (CO_2) and other Greenhouse Gases (GHGs) in the earth's atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), the observed increase in the average global temperature since the mid- 20th century is most likely due to the observed increase in anthropogenic GHGs. The IPCC has also concluded with high certainty that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems. This influence, which has caused glacier shrinkage and decline of some plant and animal populations among other things, has the power to cause further irreversible damage to these systems. Some projected future results of anthropogenic warming include (but are not limited to) increased extinction rates among some plants and animals, lessened biodiversity, flooding, decreased water availability, and increased occurrences of climate extremes.
The Food and Agriculture Administration of the United Nations (FAO) recently reported that the animal agricultural sector emits 18 percent (almost 1/5) of human induced GHG emissions worldwide, making it extremely relevant to climate change. In a breakdown of GHG emissions, the FAO reported that 9 percent of total CO_2 emissions and 35-40 percent of anthropogenic methane (CH_4) emissions are caused by the animal agricultural sector. They also wrote that 70 percent of nitrous oxide emissions come from a combination of crop and animal agriculture.

The large amount of beef produced for consumption in developed countries, such as the United States, also makes it the largest overall contributor to the animal agricultural sector's overall GGEs. However, there are various factors that go into determining the amount of emissions a cow produces, specifically the way in which the animal is farmed. There are many contrasting reports and studies attempting to determine the lowest emission beef production method: pasture- based, concentrated animal feeding operation (CAFO)/conventional, or an organic version of either. Beef consumption, regardless of production method, needs to be reduced. Beef consumption can be replaced by poultry or pork, which have significantly less emissions due to their size and digestive systems. Cattle produce high emissions regardless of how they are produced. Grass-fed cattle appear to have lower emissions compared to CAFO if all aspects of feed, production, and waste management are included, even if they take up more land. More research concerning GGEs from farm animal production in the U.S. needs to be conducted. The lack of data coming from production systems in the U.S. is very noticeable, even though the topic of GGEs and livestock production plays a significantly role in climate change.

There seems to be a consensus that poultry production has less of an effect on GGEs than other livestock production. All livestock production has a significant effect on GHG emissions, and while poultry has appeared to be lower on the scale than other meats, limiting our intake of meat is one significant way to reduce ones contribution to GGEs. While poultry production does produce many environmental impacts as well as add to GGEs, it does so to a lesser extent than beef or pork, and is thus a more climate efficient choice when linking ones diet to climate change. While this is true, it is important not to discount the fact that getting ones protein from vegetables and legumes will still have a far less significant contribution to GGEs than any livestock production.

The field of emission quantification still has uncertainties, which has raised issues between the relative emissions of pork and chicken, because particular farms may be far more emissions intensive than others; dependent on land use, where feed comes from, etc. There is still much debate over the differences in organic vs. conventional poultry production, as organic systems generally use much more land, while the conventional system will use less land, but with more use synthetic fertilizers and pesticides (from feed provisions). On the whole, agricultural systems must be evaluated on a more holistic level, incorporating human interests, animal welfare, GGEs, and other indicators of sustainability to truly be effective.

However, many organic systems take into account certain environmental factors that are ignored by conventional ones, and while this is a merely qualitative observation, it seems that organic poultry production has the possibility to be the superior alternative. Concerning areas that need more research, there still needs to be considerable work done in analyzing the relative emissions of organic/conventional poultry, as it seems there is not enough information to make definitive assertions as to which method is more climate friendly.

The comparison between poultry and egg production requires additional studies, as few have occurred on U.S. soil, while some of the published articles generally place eggs lower in terms of GGEs than poultry itself. Land use is also one of the more disputed issues in the science of quantifying GGEs among livestock production, as it is extremely difficult to surely know how much nutrients the land can take in, and what is being emitted.

The U.S. Department of Agriculture (USDA) and the Innovation Center for U.S. Dairy have partnered in efforts to help reduce GGEs. They have completed a LCA for fluid milk and have found several opportunities of where and how they can reduce emissions. All stages of the production cycle have opportunities for emission reduction. Crop production, the first stage in dairy production, contributes around 10.6 kg CO2-eq/cwt fluid milk. With better crop management techniques the dairy industry believes it will be able to sequester around two million metric tons of CO2-eq. a year. The next stage of production is milk production, which is the largest contributor of GGEs in the whole cycle. The processing sector accounts for 3.75 kg CO2-eq/cwt fluid milk and could possibly be reduced by 30 percent. Packaging of fluid milk claims around 3.5 kg CO2-eq/cwt fluid milk while retail reported 1.8 kg CO2-eq/cwt fluid milk. The United States and multiple countries in Europe are working toward lowering GGEs with well-researched strategies.

While it is well established that the meat industry is the main contributor of methane gas emissions from agriculture, it has been shown that "The global anthropogenic emissions rate for nitrous oxide is 4.4 x 1012 of N2O per year; 80% of which is due to agricultural soils."(Xiong 2006) In addition to the huge impact from nitrous oxide, much of America's produce is imported from many miles away. The farther food travels, the more carbon dioxide emissions it accrues, due to the transportation methods from producer to retailer.

There are two main issues at hand for fruit and vegetable production. First is the emissions of nitrous oxide during the growth of the crops, and second is the location of the farm sites; the further it is grown from where it is sold, the more "food miles" the produce has allotted. "Food miles" is an invented term referring to the number of miles the food must be transported in order to be sold; as distances increase, so too do GGEs.

N2O emissions from fruit and vegetable production are quite significant. Accountable factors for contributions to such emissions are primarily the amount of nitrate fertilizers used. The use of manure and urea, i.e. using cow manure to fertilize crops, contributes more to emissions than do mineral enriched nitrate fertilizers. There is a positive correlation between the amount of fertilizers used and the amount of nitrous oxide emitted from the crops, and it is most likely due to these factors that organic farms are more nitrous oxide efficient than their conventional farm counterparts. An ideal produce system, in terms of GGEs, would use little nitrate fertilizers enriched with minerals, a no tillage system, and would be local.

A brief exploration of the general theory, methods, data and analysis of some examples of current research on emissions from rice, wheat and corn production demonstrates how the complexity of quantifying food emissions currently confounds efforts to create clear, reliable guidelines for a low-emissions diet. The data from emissions studies of corn, wheat, and rice are inconclusive since there are still too many possible and significant sources of error, such as omitted processes, field emissions, and different species, climates and locations that were not accounted for and may easily confound a study's results.

Key goals of future research in this area for the purpose of developing food emissions guidelines for consumers may be; (1) definitively establishing reliable ways to quantify field emissions; (2) generating primary, location-specific LCA inventory data for rice, wheat and corn production in the US; (3) developing more robust and reliable methods of data collection and development, such as real-time emissions monitoring equipment designed specifically for large scale agriculture (methods superior to small scale experiments coupled with reliance on limited, generalized databases that make multiple assumptions); and, (4) developing standardized, compatible and comparable units. Ultimately, these units must be comprehensible to food consumers.

Beef

Introduction

Since the 18th century, human activity has increased the concentration of carbon dioxide (CO_2) and other Greenhouse Gases (GHGs) in the earth's atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), the observed increase in the average global temperature since the mid- 20th century is most likely due to the observed increase in anthropogenic GHGs. The IPCC has also concluded with high certainty that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems. This influence, which has caused glacier shrinkage and decline of some plant and animal populations among other things, has the power to cause further irreversible damage to these systems. Some projected future results of anthropogenic warming include (but are not limited to) increased extinction rates among some plants and animals, lessened biodiversity, flooding, decreased water availability, and increased occurrences of climate extremes.

Although the majority of the general public is aware of the increase in GHG emissions, many are unaware of the sources of these emissions. The Food and Agriculture Administration of the United Nations (FAO) recently reported that the animal agricultural sector emits 18 percent (almost 1/5) of human induced GHG emissions worldwide, making it extremely relevant to climate change. In a breakdown of GHG emissions, the FAO reported that 9 percent of total CO_2 emissions and 35-40 percent of anthropogenic methane (CH_4) emissions are caused by the animal agricultural sector. They also wrote that 70 percent of nitrous oxide emissions come from a combination of crop and animal agriculture. Beef cattle production, in particular, plays a large role in producing these emissions. Because cattle are large, resource intensive animals with ruminant guts, they produce the largest amount of GHG emissions as individual animals compared to other common livestock (i.e. poultry, pigs). In addition, the large amount of beef produced for consumption in developed countries, such as the United States, also makes it the largest overall contributor to the animal agricultural sector's overall GHG emissions. However, there are various factors that go into determining the amount emissions a cow produces, specifically the way in which the animal is farmed. There are many contrasting reports and studies attempting to determine the lowest emission beef production method: pasture- based, concentrated animal feeding operation (CAFO)/conventional, or an organic version of either.

This review examines several academic articles and an official report dealing with livestock production methods in order to mediate seemingly conflicting opinions about GHG emissions (within beef production) and to draw informed conclusions on GHG mitigation strategies.

Approaches To Quantifying GHG Emissions

Methods

Since so much data is available about beef production, the majority of the articles reviewed were themselves collections of recent and relevant data (worldwide and regional) compiled and interpreted by the authors/experts. This is true of all the articles with the exception of two; one where the authors determined thief own complex system and formulas for determining GHG emissions related to livestock manure management and another which used surveys and anecdotal evidence.

In the article *Global Farm Animal Production and Global Warming* by Koneswaran and Nierenberg, the authors utilize a number of sources with the objective of "synthesizing and expanding" on data about farm animal production's contribution to climate change. They begin their article with a brief introduction of global warming and anthropogenic influences on climate change. In their discussion, they analyze scientific literature on farm animal production and documented GHG emissions and mitigating strategies. They use various subsections, such as "CO_2 emissions from animal agriculture," to organize their information and focus on each individual GHG and also to cover non-GHG specific factors like deforestation, and human disease and hunger. It is important to note that Koneswaran and Nierenberg include and consider data about the production of the grain used to feed cattle, waste management processes, and food miles, which are not considered in all other articles. Also included is a brief strategies section, which covers current projects, research, and regional policies dealing with mitigating GHGs related to animal agriculture.

The Avery and Avery piece, entitled *Beef Production and Greenhouse Gas Emissions* is not an article, but rather a short response to the Koneswaran and Nierenberg article discussed previously. Avery and Avery look critically at Koneswaran and Nierenberg's data analysis methods and conclusions on beef and introduce new data that contradicts the original author's conclusions.

Similar to the Koneswaran and Nierenberg article, *The Greenhouse Burger*, by Nathan Fiala is also a compilation of data from various sources. However, Fiala's article, which was published in Scientific American, is less data intensive due to its need to be accessible a wider and more general audience. In his brief article, Fiala describes how CAFO beef production systems contribute to CO_2 emissions and the other two lesser known GHGs, CH_4 and N_2O in their CO_2 equivalent forms. He also uses maps, charts, graphs, and illustrations to colorfully present data from various studies that also show how beef production leads to GHGs and how much beef is consumed in the United States in comparison to other countries.

The IPCC report reviewed, which was published as part of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* differs entirely from the previously mentioned articles. The purpose of the article is to provide a method of measuring GHG emissions from manure management and enteric fermentation that considers the animal and its lifespan, digestive system, diet and feeding system, and the climate and details of the region. It has a subsection for each GHG, where it first explains all the factors that can be used in determining the emissions followed by an easy to read "decision tree," which shows the steps that need to be followed to ensure the right formula/system is used when calculating emissions.

Lastly, for the Verge et al article, *Greenhouse Gas Emissions from the Canadian Beef Industry*, various methods were used, some in line with methodology "described for the Canadian dairy sector." Specifically, they used provincial beef cattle populations from the agriculture census records for 1981-2001(it should be noted that these surveys occur every five years) for determining population demographics. The beef crop complex (i.e. how much of the crops are reserved for beef production) and energy-based CO_2 emissions had to be determined using formulas created by the authors that utilized the data in the census records. The N_2O and CH_4 emissions were calculated using the formulas developed by the IPCC in the article mentioned above with the data provided in the census records. Since they did not have data for some of the years, they had to estimate using what they call "anecdotal evidence," which is not further explained.

Findings

For the articles that compiled data, the findings are synonymous with the authors' conclusions, or how they interpreted the data, and these conclusions varied dramatically.

Koneswaran and Nierenberg conclude that immediate changes are needed in current animal agriculture practices and consumption patterns in order to mitigate GHG emissions. Specifically, they feel that burning fossil fuels to produce fertilizers for feed crops (up to 41 million metric tons/year), fossil fuels expended for CAFOs (up to 90 million metric tons/year) and production and transportation of livestock (GHG equivalent of 36.4 kg CO_2/ 1 kg beef) are what contribute the most to worldwide CO_2 emissions. Also, cattle fed grain diets and may have higher methane emissions than pasture based ones, and the large amount of cattle being produced cause a high amount of nitrous oxide emissions from manure and urine and from fertilizer in grain crops CAFO cattle consume.

One mitigating solution that they particularly champion is the consumption of pasture-fed cattle or organic feed cattle over CAFO conventionally produced beef, which can have about half the methane emissions and lower nitrous oxide emissions than conventional. However, other studies have shown that typical nonorganic beef production in the United States actually has less CO_2 emissions than the Swedish organic beef system on which Koneswaran and Nierenberg based their initial statement (Avery and Avery A375). Also mentioned by Avery and Avery is the fact that grain-fed cattle is at least three times more land efficient per pound of beef compared to grass-fed beef. In fact, they also state that converting all beef production to grass based would require an additional 26.6 million acres of pasture to produce the same beef output. (A375) Verge et al. also have similar findings; specifically, that the emissions intensity has decreased (from 16.4 to 10.4 kg of CO_2 equivalent per kg of live cow from 1981 to 2001) as feedlot operations have increased and become more efficient. However, Verge et al. does not account for any GHG from processing, storing or shipping the beef, which are included in the Koneswaran and Nierenberg data.

Also mentioned was that new technologies for large scale livestock production farms, such as anaerobic digesters, which capture methane from manure to use as energy, or using animal waste to create biofuels can help mitigate their high GHG emissions. (Koneswaran and Nierenberg, 580; Fiala, 73) Koneswaran and Nierenberg, and Fiala also conclude that consuming less farm animals is one of the most important steps in mitigating animal agriculture GHG emissions. (581; 73)

Although the IPCC report serves as a guide for understanding and using data rather than producing data, the formulas and systems that are in the report give valuable information about what is actually relevant when calculating emissions related to manure management. For example, beef cattle are almost always evaluated on a Tier 2 or Tier 3 level (specifically for higher GHG emitting animals along with the presence of more detailed information) because of their enteric fermentation and their ruminant digestive system, which are not found in poultry or pigs and contribute to methane emissions (10.24). Also pasture grazing and grain fed cattle have markedly different GGE contributions and may be ranked on separate tiers depending on the GHG being evaluated (10.10).

Conclusion

The most certain and clear conclusion is that beef consumption, regardless of production method, needs to be reduced. Beef consumption can be replaced by poultry or pork, which have significantly less emissions due to their size and digestive systems. Cattle produce high emissions regardless of how they are produced. That being said, grass-fed cattle appear to have lower emissions compared to CAFO if all aspects of feed, production, and waste management are included, even if they take up more land. Ideally, much less beef cattle would exist, and the beef being produced would come from pasture fed cattle.

It is also clear that more research concerning GHG emissions and farm animal production in the US needs to be conducted. The lack of data coming from production systems in the US is very noticeable, even though the topic of GHG emissions and livestock production plays a significantly role in climate change.

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Poultry

Introduction

The purpose of this literature review is to shed light on the issue of poultry production in relation to greenhouse gas emissions and climate change, taking into account CO_2, CH_4, and N_20 emissions stemming from poultry production systems. The issue of livestock production in correlation to climate change has been considered extensively amongst academic researchers. This review highlights five exemplary articles that attempt to quantify the impacts of poultry production systems. Some of these articles use the life-cycle analysis (LCA) method of quantification, taking into account all inputs affecting emissions from the beginning of production up to and including transportation, while one study uses the emergy approach. The main issue this review is concerned with is making connections between the poultry production system, climate change, and how greatly this system affects climate change in comparison to other livestock, while also highlighting gap areas in research that need to be addressed with more depth. This must be done through more research efforts that attempt to quantify GGEs from livestock production, as there has yet to be a method that can calculate these data with unequivocally precise results. The articles chosen will be analyzed through a discussion of the theories, methods and data used within each, in an attempt to highlight useful conclusions that have been put forth, and to make suggestions on what more needs to be done in the field.

Approaches To Quantifying GHG Emissions

Theories

While there is debate around specific gap areas in poultry research (addressed later in this paper), there seems to be a consensus that poultry production has less of an effect on GGEs than other livestock production. The articles this paper reviews promote theories that point to the fact that decreasing ones consumption of meat products can have a great effect on individual contributions to climate change. For instance, through using the IPCC's approach to calculating GGEs, Carlsson-Kanyama and Gonzales (2009) promote the theory that a plant based diet, or a diet including animals without enteric fermentation (major source of methane) can significantly decrease ones impact on GGEs. Furthermore, de Vries and de Boer (2010) theorize that poultry production creates less of an impact than pork or beef, however the main differences in environmental impact can be traced to methane production, differences in feed efficiency, and differences in reproduction rates. This study also makes connections between poultry production and egg production, concluding that the high water content of eggs translates into less GGEs than the production of the chicken itself.

In an assessment of the U.S. poultry production system via LCA analysis, Pelletier (2008) promotes the fact that all inputs, from all stages must be accounted for, and goes forth to promote a theory that places feed requirements as the main source of energy use in the industry. He also highlights the fact that "interlinked industrial activities comprise the broiler supply chain," and that many studies only account for on-farm emissions while ignoring system wide emissions. These studies all link livestock production to climate change and frame it as a serious contributor to GGEs, which must be reformed in a world in which population is rising, as is the demand for high protein products.

Straying away from the more life cycle oriented approaches used by the previous three published works, Castellini et al. (2006) use an Emergy analysis approach to compare the differences of organic and conventional poultry on two distinct Italian-based farms. The theory in this study is comprised of the notion that organic production is an important strategy to implement (no chemical fertilizers, pesticides, etc.), and that the organic approach can significantly reduce emergy flows, and thus emissions. This study will be analyzed in greater detail in the section pertinent to organic vs. conventional poultry production systems.

An interesting theory comes from a paper by Garnett (2009), in which she theorizes that the LCA method of quantifying GGEs from livestock often times is inaccurate due to the vast complexity of the food system. The author offers three additional perspectives that will be discussed in detail in a following section addressing the shortcomings and potential problems with LCA studies (Note: this study will not be discussed in "methods" or "data" because it was not technically a study, but a review with policy recommendations). While these studies have addressed various topics ranging from life cycle analysis to comparing poultry to other livestock systems contribution to GGEs, the consensus among theories is clear: that all livestock production has a significant effect on GGEs, and while poultry has appeared to be lower on the scale than other meats, limiting our intake of meat is one significant way to reduce ones contribution to GGEs.

Methods

In arguing that a more plant-based diet can have great effects on ones GGE contribution, Carlsson-Kanyama and Gonzales analyzed 22 food items from Sweden in a life cycle method, considering emissions during cultivation of the feed required for rearing the animals, along with processing, transportation, and any inputs related to the production of poultry. The analysis included CO_2, CH_4, and N_20 emissions, all in the form of CO_2 equivalents/kg of product. de Vries and de Boer chose 25 LCA studies they found represented the entirety of the livestock production system, and analyzed the results through calculating a functional unit (FU), in order to have a basis to compare the many studies. This process was done by first recalculating the results of each study to an FU of 1 kg of live weight, next to 1 kg of edible product, and a third recalculation was made to translate the FU into 1 kg of protein. From this FU, came calculations of each livestock products Global Warming Potential (taking into account CO_2, CH_4, and N_20) as well as acidification potential, eutrophication potential, use of land, and energy use.

Pelletier used LCA guidelines to estimate GGEs (CO_2, CH_4, and N_20) and included "direct inputs and emissions associated with the production of poultry feed ingredients including fuel use for field operations and crop drying, the production of fertilizers/soil amendments, seed and pesticides, as well as nitrous oxide and ammonia emissions from fertilizers and crop residues for agricultural crops; crop processing; poultry processing and rendering to produce poultry fat and by-product meal; and reduction fisheries and fishmeal reduction plants," (Pelletier 2008, p. 68). This study was perhaps the most comprehensive in detailing what it did and did not account for, reflecting the quality of work and amount of time spent to produce usable results. Castellini's emergy analysis approach is similar to an LCA as it takes into account all of the inputs that were necessary in both the organic and conventional farms. Some examples of what the study encompasses include: human labor, antibiotics, potable water, feed and feed additives, irrigated maize, soil erosion, and sanitization. Therefore while it is not technically an LCA assessment, it still can display valuable information about the efficiencies of each system, and help quantify which sector is using the most amount of emergy.

Data

In the Carlsson-Kanyama study the data for poultry emissions calculated are as follows (kg CO_2 equivalents/kg product): CO_2 = 3.1, CH_4 = .01, N_2O = 1.2. The study also quantified emissions from production of eggs in the same metric: CO_2 = 1.7, CH_4 = .04, N_2O = .74. These numbers mean little alone, however when compared to beef (CO_2 = 6.9, CH_4 = 17, N_2O = 6.6), it becomes clear that chicken production is associated with much less GGEs than beef production, and highlights the importance of taking into account enteric fermentation of ruminant animals. The broad scope of products in this study is helpful in comparing poultry production emissions to other food products, and points to the conclusion that as far as livestock production is concerned, chickens have the least impact on climate change. The results from de Vries and de Boer's comprehensive LCA study were broken up into five impact categories, however this review will only examine emissions, which were all combined as Global Warming Potential. The study used three LCA assessments regarding poultry production, two conventional and one free-range system. CO_2, CH_4, and N_2O emissions were summed up as a single Global Warming Potential (GWP), which for poultry was 4043 kg CO2-e on average. This number compared to the average beef GWP of 18,275 kg CO2-e highlights the vast amount of GHGs emitted by cattle, and the fact that poultry is one of the more GHG efficient ways to produce protein from livestock. This study also concluded that because of the higher water content of eggs, they tend to consistently have a lower impact on GGEs than actual production of the chickens themselves. While these results are telling, the study did point out that the way farmland is used may have great effects on GGEs, and various farms may have greater impacts than others.

Pelletier's LCA study on U.S. poultry production "found that feed provision accounts for 80 percent of supply chain energy use, 82 percent of GGEs, 98 percent of ozone depleting emissions, 96 percent of acidifying emissions and 97 percent of eutrophying emissions associated with the cradle-to-farm gate production of broiler poultry" (Pelletier, p. 67). In examining this huge amount of emissions from feed closer, it seemed that the production of corn and soybeans were the biggest contributing factor in GGEs within the U.S. poultry industry. (Castellini's study will be discussed in the organic vs. conventional section).

Analysis

These three studies all quantified emissions from poultry production through similar but slightly different methods, while all coming to a similar conclusion. While poultry production does produce many environmental impacts as well as add to GGEs, it does so to a lesser extent than beef or pork, and is thus a more climate efficient choice when linking ones diet to climate change. While this is true, it is important not to discount the fact that getting ones protein from vegetables and legumes will still have a far less significant contribution to GGEs than any livestock production. However, when it comes down to the production of animals for protein consumption, chickens as well as eggs both have lower impacts on GGEs than other livestock systems. It is still important to keep in mind that the field of emission quantification still has uncertainties, which has raised issues between the relative emissions of pork and chicken, because particular farms may be far more emissions intensive than others; dependent on land use, where feed comes from, etc. While it can be said that poultry production generally has less of an impact than other meats, it is crucial to consider the large amounts of variables involved in farming these animals, and that decisions such as where one buys feed and how they dispose of manure may differ from farm to farm, and thus have varying impacts.

Organic vs. Conventional

With limited information on the impacts of organic and conventional poultry production, I have turned to examining Castellini's work in Italy comparing one organic and one conventional farm in terms of emergy analysis. As mentioned earlier, this emergy analysis accounts for the inputs involved in poultry production, ranging from human labor to artificial fertilizer used for growing feed. The results of this study were rather astounding, as the total emergy flow from the organic system was 92.16 sej (solar emjoules), compared to the conventional system that was 724.12 sej, a vast difference. The solar emjoule unit is representative of solar transformity, and "is the emergy per unit flow or unit product and it has been proposed as a measure of the position of a given item in the thermodynamic hierarchy of the planet" (Castelini, 2006, p.344). However in both of the systems it is interesting to note that over 50 percent of the emergy came from feed requirements. These findings were consistent with the work of Pelletier, and stressed the importance of evaluating the impact of growing feed for livestock and ensuing effects for GGEs. While the study clearly shows that organic poultry has advantages in emergy analysis, there is still much debate over the differences in organic vs. conventional poultry production, as organic systems generally use much more land, while the conventional system will use less land, but with more use synthetic fertilizers and pesticides (from feed provisions). On the whole, agricultural systems must be evaluated on a more holistic level, incorporating human interests, animal welfare, GGEs, and other indicators of sustainability to truly be effective. It is difficult to conclude which system is better in the case of poultry production, as this is the only study evaluated in this literature review, and took place on smaller farms in Italy rather than within the larger production systems characteristic of the United States. It is because of this fact that we cannot recommend either conventional or organic poultry over one another in terms of GGEs, due to a lack of data. However what can be said is that many organic systems take into account certain environmental factors that are ignored by conventional ones, and while this is a merely qualitative observation, it seems that organic poultry production has the possibility to be the superior alternative.

LCA Shortcomings / Gap Areas in Research

While LCAs offer significant amounts of information regarding the environmental impacts of food systems, the complex nature of food production is important to consider, as even LCA studies can hide valuable facts. This is the argument of the final article to be discussed in this review, by Garnett. She believes that because of the complexity of our food system, LCAs of livestock generally offer a limited understanding of the GHGs associated with livestock production. Garnett offers three additional perspectives that should be implemented within the LCA analysis in order to provide a more comprehensive view of food systems. First is an understanding of the indirect second order effects of livestock production on land use change and associated CO_2 emissions; second is comparing the opportunity cost of using land and resources to rear animals with their use for other food or non-food purposes; and finally third is considering how truly necessary is livestock to the human population (do we really need mass quantities?). All three of these perspectives can be helpful in providing a more thoughtful, broad analysis of poultry production, as the uncertainties are certainly vast. Garnett's call for more thought on opportunity cost of land use is particularly relevant, as the studies we reviewed pay close attention to the large contribution that feed requirements have towards increasing GGEs. It is important to consider planting crops to be fed to humans, or planting crops to be fed to animals and then to humans, with much greater use of energy. Garnett also believes LCAs can give a distorted impression of sustainability of pigs and chickens above ruminant animals; while they do have lower life-cycle emissions, their contribution to GGEs cannot be discounted entirely. Most explicitly, Garnett states that policy "needs to go beyond approaches that anticipate demand and start considering what people actually need to ensure equitable sustainable development" (Garnett, p.500). While Garnett's suggestions are helpful in realizing the limits of LCA studies, Pelletier believes LCAs are the most urgently needed forms of analysis. While recognizing their limits, he believes that they can still influence policies in the right direction in helping mitigate GGEs from livestock production.

Concerning areas that need more research, there still needs to be considerable work done in analyzing the relative emissions of organic/conventional poultry, as it seems there is not enough information to make definitive assertions as to which method is more climate friendly. Another area that may need more attention is the distance that feed travels to get to a poultry farm, and how this feed has been grown, which is riddled with uncertainties, as often times these factors are generalized for the sake of a study. Moreover, the comparison between poultry and egg production requires additional studies, as few have occurred on U.S. soil, while some of the published articles generally place eggs lower in terms of GGEs than poultry itself. Land use is also one of the more disputed issues in the science of quantifying GGEs among livestock production, as it is extremely difficult to surely know how much nutrients the land can take in, and what is being emitted. Although there are many uncertainties within this field, the papers that have been reviewed all have employed sound science, and while numbers may be relative, they nonetheless provide insight on approximating how our diets contribute to climate change, and should be used to influence policy that is focused on addressing emissions issues from livestock production in particular.

Conclusion

The purpose of this review was to reveal what work has been done thus far in quantifying GGEs from poultry production systems. From the articles reviewed, it is fair to say that there is a consensus that as far as livestock in concerned, poultry is one of the lower emitters, as ruminants and pork have shown to have more emissions associated with them. Eggs, while needing additional research, also appear to have lower emissions than other animal products including chickens themselves, due to higher water content. While the data has uncertainties attached to it, one can lessen their own contributions to GGEs by replacing red meat with poultry. While this may be true, it is important to realize that even though the relative emissions of poultry have been shown to be less than other livestock, a vegetable based diet with limited meat consumption will still be the most climate efficient.

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Dairy

Introduction

In the United States agriculture is one of the biggest contributors to global emissions of GHGs and accounts roughly for one third of the United States total emissions. Dairy farming in particular is responsible for large emissions of methane (CH4), nitrous oxide (N2O), as well as carbon dioxide (CO2). This review compares several articles based on research collecting emission rates for these gases. Mitigation strategies were introduced to help lower these emissions for dairy farms. The purpose of this review is to make meaningful comparisons between different dairy products that are produced in different operating systems. Sometimes organic products generate more GHGs than conventional because they have lower amounts of yields and have a higher percentage of land usage. Most of the Life Cycle Assessment (LCA) research that looks at conventional and organic has been conducted in several different regions in Europe but not in the United States.

Theory for Olesen et al. Article

Olesen et al. discuss how 80 percent of global anthropogenic N2O emissions are from agriculture and that 40 percent of that comes from manure management. Ruminant animals also cause methane emissions through manure handling processes and enteric fermentation. Making the connection between global anthropogenic emissions and dairy production builds a bridge linking the problem to an understanding how emissions are created. The research design that Olesen et al. decided to use complimented their overall theory that there is much room for improvement on reducing dairy related emissions.

Methods

The FarmGHG model that Olesen et al. chose included carbon and nitrogen flows that were moved into and out of the farm as well as internal flows in each stage of their design. They evaluated 15 different systems, 8 organic and 7 conventional farms, which were scattered around "five European dairy farming regions [and] were identified to reflect differences in livestock density and differences in grazing/feeding systems" (Olesen et al., 212). Within the farms they distinguished two different types of livestock, cows and the young stock (heifers). The team also evaluated the housing provided to the livestock, manure storage, fields and crops, and pre-chain emissions. In each of the five different regions they assumed that cows achieved the same milk yield as other farms in their same region whether it was conventional or organic. Most of the farms operated on the same manure type which made comparing emissions in this section easy. The FarmGHG model covers many of the same assessments as a LCA would however there are many variables not included in this model that need to be emphasized in future research.

Assumptions and Uncertainties

The purpose of the FarmGHG model is to gather data on the production process of European dairy farms and report related GGEs. "The farms were assumed to be operated by best management and not to export manure" (Olesen et al., 208). This is a huge assumption because not all farms actually do operate by best management; this assumption does not allow accounting of emissions that result from systems operating under best management. Other practices that were assumed include estimated annual feed requirements for cows, no estimations of methane emissions from certain manure procedures, no seepage occurred from solid manure or deep litter, and energy costs from farm machinery and buildings were not included in the model. Even when farms are operating under good management practices, seepage from any kind of manure can occur resulting in emissions of GHGs. These are some topics that could be addressed in future studies.

Data and Results

The results from the FarmGHG methodology were compared to IPCC (1997) and IPCC (2000) methodology for simulated emissions. They found that N2O emissions were higher in the default FarmGHG model than in the IPCC (2000) methodology while CH4 emissions were lower. "Nitrous oxide contributed on average about 49% of the total emissions in terms of global warming potential, and CH4 contributed about 42%" (Olesen, 214). Olesen et al. made a correlation between increasing nitrogen surplus with increasing amounts of livestock on both types of farms. The higher the surplus of nitrogen, most likely from leaching, that was found on the farms, the higher the N2O emissions. Methane emissions were mostly constant throughout the year for enteric fermentation, except for during summer months due to manure handling. Higher day temperatures yield more methane emissions due to anaerobic digestion and decomposition.

Olesen et al. does not explicitly compare the different GHG CO2-equivalent results between organic and conventional systems. They did however include a graph that listed simulated emissions of carbon dioxide, nitrous oxide, and methane in CO2-eq. units per hectare per year. We plugged the FarmGHG data results into a spreadsheet and found that organic had lower CO2-eq. for all three gases (CO2: organic 0.34, conv 1.21. CH4: organic 2.95, conv 4.17. N2O: organic 2.59, conv 5.7) than conventional did. All units are in Mg CO2 eq/ha/year and the spreadsheet can be found in Appendix 1. Garnering this data in units of kg per milk instead of hectare per year would allow for more understanding and comparisons to be made.

Theory for Weiske et al. Article

The FarmGHG model created a system to evaluate a group of conventional and organic farms that represented all different regions of Europe. The article Mitigation of Greenhouse Gas Emissions in European Conventional and Organic Dairy Farming by Weiske et al. concentrates on developing mitigation strategies for these model farms in order to reduce GGEs. The connection between agricultural activities and anthropogenic emissions is stated clearly in the beginning of the article. Most of these emissions are from management-related activities on the farm and have potential for reducing emissions if new techniques can be implemented cost effectively. This article and the previous article written by Olesen et al. demonstrate that there is a strong correlation between increasing levels of GGEs and anthropogenic causes.

Methods

The FarmGHG model, which is based upon the same model and results that were found in the Olesen et al. article, surveys seven conventional and organic model farms. "These 14 defined model farms were chosen as typical farm types for different European regions" (Weiske et al., 222). The study examined four different mitigation strategies that could be used on both types of farms and the changes in emission rates were calculated through carbon and nitrogen budgets for the whole farming system. The selected mitigation measures were: optimized lifetime efficiency of dairy cows, frequent removal of manure and scraping systems, biogas production by anaerobic digestion, and improved manure application techniques.

Through plenty of research understanding of optimized lifetime efficiencies of cows, Weiske et al. was able to create replacement rates and ideas of what to do with surplus heifers on the farm. Having extra heifers on the farm increases your emissions and they are not producing milk yet. Daily removal of manure was applied to slurry-based systems that had regular removal periods that lasted longer than one day. For biogas production by anaerobic digestion several different scenarios were tested for possible emission reduction. With biogas production it will "achieve both a reduction in CH4 emissions and a substitution of fossil fuels, which reduces CO2 emissions" (Weiske et al., 223). The last mitigation strategy evaluated was improved manure application techniques through a trail hose and by injection. These application methods help reduce the amount of imported fertilizer which reduces the overall surplus of nitrogen. The strategies that were implemented did not reduce emissions in all areas for both types of farms and found that organic does not always mean fewer emissions.

Data and Results

The conventional farms that were simulated in the model for different replacement rate combinations ranged from 1.3 to 1.7 kg CO2-eq. per kg milk and from 1.2 to 2.0 kg CO2-eq. per kg milk for organic farms. When the results were averaged they found that organic farms produced 10 percent higher emissions than conventional farms. The RR3 model, a combination of a reduction in replacement rate and selling heifers just after birth, was found to have the highest reduction in GGEs out of all the other models by 10.9 percent for conventional and 11.7 percent for organic. On average a conventional farm could see a 4.5 Mt CO2-eq. per a (a= Atlantic region models) fewer emissions using the RR3 model while organic farms saw a 0.17 Mt CO2-eq. per a. Frequent removal of manure showed a possible emission reduction in animal houses by 97 percent, however also caused a large increase in emissions in manure stores. It is important to note that even though it caused an increase in emissions for manure stores it improved the air quality and production performance on the farm. The overall scraper system that was used to remove the manure daily generated more GGEs in electricity than was imported through nitrogen fertilizers, which caused an increase in prechain emissions.

Biogas production by anaerobic digestion has one of the highest potentials for emission reduction on the farm systems. The methane that is generated by this procedure substitutes for fossil fuel usage. All of the farm models were 50 ha, however biogas production is only economically viable for farms the size of 100 ha. When conventional farms were modeled (100 ha) to use the total amount of thermal energy created, the possible emission reduction could be up to 24 Mt CO2-eq per a. The mitigation potential for organic farms was much smaller at 1.2 Mt CO2-eq per a, at best. The potential is much smaller because if farmers improved manure application techniques it could increase nitrogen leaching which leads to greater N2O emissions. The main variable that is not fully accounted for and needs to be pointed out in this study deals with the frequent removal of manure. "There are no European statistics available on manure management practices in dairy farming… thus a large uncertainty associated with the evaluation of the regional efficiency of this mitigation measure" (Weiske et al., 227). Methane and nitrous oxide emissions resulting from manure management need to be taken into consideration to complete a full research assessment and potential of mitigation strategies.

Theory for Thomassen et al. Article

The overall theme of these article's theories is that agricultural activities have large environmental impacts that need to be addressed. The article Life Cycle Assessment of Conventional and Organic Milk Production in the Netherlands, by Thomassen et al., examines the whole production system from beginning to end and assesses the environmental impact. By evaluating the whole life cycle they are able to identify hot spots in both conventional and organic systems. There are four stages to the life cycle assessment (LCA): goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results.

Methods

The first stage of the LCA is used to determine the working plan of the entire LCA. In order to compare conventional against organic you need to measure the systems on the same functional unit, which is milk production. The baseline impact categories chosen by Thomassen et al. include: land use, energy use, climate change, acidification, and eutrophication. The second step is "inventory analysis [which] consists of the collection of data concerning resource use, energy consumption, emissions and products resulting from each activity in the production system" (Thomassen et al., 98). In this stage each process is further analyzed to make sure every step in production is accounted for. Once all the data is collected it is then put through an impact assessment where environmental effects are evaluated qualitatively and quantified in terms of a common unit. After all of the information is collected it is then put through interpretation and analysis to come up with conclusions and recommendations. The methodology used here is consistent with how other LCAs conduct their research because it provides clear results from their study.

Data and Results

In the land use impact category it shows that organic systems use more amounts of land (1.8m^2/kg) than conventional systems (1.3m^2/kg) because of lower yields from no use of artificial fertilizer and lower livestock density. Organic systems also used larger amounts of direct energy use than conventional. However, the "total energy use was higher for the conventional system (5.0 MJ/kg) than for the organic (3.1 MJ/kg)… due to a higher indirect energy use" (Thomassen et al., 101). Total eutrophication for both on-farm and off-farm totals was lower for organic (0.07 NO3-eq/kg) than conventional (0.11 NO3-eq/kg). This is mostly due to volatilized ammonia, phosphate, and nitrate leaching through manure management and application. Total acidification was higher for organic (10.8 SO2-eq/kg) due to higher on-farm acidification than for conventional (9.5 SO2-eq/kg). Climate change is the last impact category in the LCA and it explains each system's Global Warming Potential and the data CO2-equivalent units. The organic system came out to have a slightly higher Global Warming Potential with 1.5 kg CO2-eq/kg while the conventional system came to 1.4 kg CO2-eq/kg. From reviewing these three articles, it becomes increasingly clear how hard it is to make meaningful comparisons between these two systems. From the results it seems that there is still much discussion to be had in Europe, and elsewhere, over whether organic or conventional farms produce more GGEs. We do know that there is room for improvement on moving towards emitting fewer emissions. In the United States the dairy industry has set a goal to reduce GGEs by 25 percent by the year 2020.

Theory, Methods, and Data for USDA

The U.S. Department of Agriculture (USDA) and the Innovation Center for U.S. Dairy have partnered in efforts to help reduce GGEs. They have completed a LCA for fluid milk and have found several opportunities of where and how they can reduce emissions. Most of the mitigation strategies are the same as the ones used in the models mentioned above and all stages of the production cycle have opportunities for emission reduction. Crop production, the first stage in dairy production, contributes around 10.6 kg CO2-eq/cwt fluid milk. With better crop management techniques the dairy industry believes it will be able to sequester around two million metric tons of CO2-eq. a year. The next stage of production is milk production, which is the largest contributor of GHG emissions in the whole cycle. The graph that shows how much kilograms of CO2-eq is from milk production axes were not labeled and therefore cannot be reported. The same problem occurred in the transport to processor stage. The processing sector accounts for 3.75 kg CO2-eq/cwt fluid milk and could possibly be reduced by 30 percent. Packaging of fluid milk claims around 3.5 kg CO2-eq/cwt fluid milk while retail reported 1.8 kg CO2-eq/cwt fluid milk. The United States and multiple countries in Europe are working toward lowering GHG emissions with well-researched strategies. Contacting the researchers working within this policy will be beneficial in retrieving emission rates for the stages that were missing as well as other helpful statistics.

Conclusion

The information provided in these articles is very useful to help initiate the mitigation process. However, there is still a lot of misunderstanding as to whether organic or conventional farms are the best answer. With an increasing population, there is a growing demand for reasonable conclusions. Policy makers need to find the right balance in order to provide people with healthy food options that are also healthy for the environment. LCA studies seem especially promising for linking diets to climate change and for finding ways on how to manage and achieve best practices. Researchers need to consider themselves as a link of a larger grid than just conducting research for their country. We need to be able to communicate, share information freely, and report results that hold meaning and understanding to everyone. Coming up with a way to report data in identical units could be extremely helpful for comparisons against production systems in the United States to those in Europe. By sharing information and research we can tackle problems quicker, make changes earlier, and have more chances to evaluate the results.

Appendix 1

Mg CO_2-eq/ha/year

	Organic	Conventional
CO_2		
	0.4	1.5
	0.3	1.9
	0.3	1.3
	0.3	0.9
	0.3	1.1
	0.3	0.7
	0.4	1.1
	0.4	
Range	0.3-0.4	0.7-1.9
Average	0.3375	1.214285714
CH_4	4.7	5.6
	2.6	5.2
	2.4	5.4
	2.6	3.8
	2.3	3.5
	1.1	2
	4.5	5.5
	3.4	
Range	1.1-4.5	2-5.6
Average	2.95	4.171428571

	Organic	Conventional
N_2O	3.4	6.5
	2.9	8.6
	3.2	6.3
	2.9	4.8
	2.9	4.8
	1.6	2.8
	3.8	6.1
	4	
Range	1.6-3.8	2.8-8.6
Average	2.5875	5.7

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Produce

Introduction

Climate change is a serious threat facing society today, many facets of which stem from anthropogenic issues. In specific, the agricultural sector is an enormous contributor to greenhouse gas emissions. This review explores the various climate impacts of different methods of production for fruits and vegetables, specifically the net emissions of GHGs, such as methane, nitrous oxide, and carbon dioxide, in order to understand the repercussions of each methodology.

Theory

There are three primary GHGs with which this paper is concerned: methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). While it is well established that the meat industry is the main contributor of methane gas emissions from agriculture, it has been shown that "The global anthropogenic emissions rate for nitrous oxide is 4.4 x 1012 of N_2O per year; 80% of which is due to agricultural soils."(Xiong 2006) In addition to the huge impact from nitrous oxide, much of America's produce is imported from many miles away. The farther food travels, the more carbon dioxide emissions it accrues, due to the transportation methods from producer to retailer.

Of course in fruit and vegetable production there are many processes which can be performed in different ways. Petersen (2006) compare and contrast conventional and organic farming strategies, employing a theory that promotes organic methods as a more climate-minded practice. Similarly, Grant (2004) compares different soil treatments, such as soil tilling and fertilizer use, operating under the assumption that soil treatments are an underestimated contributor to the emissions of farming.

Canals (2006) adopts a much broader look at the production processes of fruit and vegetables. The theory at work in this article claims that the entire farm system produces GHGs, and hence, the entire life-cycle of a crop must be examined for fruitful and meaningful data. This LCA (life-cycle assessment) explores many facets of fruit and vegetable production, including all of the necessary machinery, pesticides, and irrigation. To fully complete such an assessment, there should be a quantification of GGEs contribution for post-production of fruits and vegetables. Weber (2008) examines the average impact of the location of farms in relation to where the produce is sold, the underlying theory being that the post-production shipping contributes greatly to carbon dioxide emissions, and that choosing to buy locally grown food is an easy way to lessen the climatological impact from eating fruits and vegetables.

Methods

There are two main issues at hand for fruit and vegetable production. First is the emissions of nitrous oxide during the growth of the crops, and second is the location of the farm sites; the further it is grown from where it is sold, the more "food miles" the produce has allotted. "Food miles" is an invented term referring to the number of miles the food must be transported in order to be sold; as distances increase, so too do GGEs.

These two aspects of fruit and vegetable production have been researched in varying ways in six studies.

For all studies, the amount of nitrous oxide emitted by crops of vegetables was determined by use of manually operated static chambers with a permanent base and a removable lid of aluminum or PVC covered with reflecting material with three or four reps. The N2O flux was calculated by using a temporal increase in N2O concentration in the air chamber with time. However, these studies did vary in a number of ways. In a study in China, baby bok choy, radishes, celery and lettuce, were all recorded, with measurements taken in triplicate once a week (Xiong 2006). Another study compared three different soil textures; sandy loam, loam, and clay loam and contrasted the net nitrous oxide flux in each of the soils (Grant 2004). In Europe, nitrous oxide emissions were measured in both organic and conventional crop rotations in five countries: Austria, Denmark, Finland, Italy, and the UK. Each of these crop rotations was measured 15, 22, 26, 26, and 25 times respectively over a year-long period (Petersen 2006). However, nitrous oxide is emitted in fluxes, and the static chamber method cannot measure all of the emissions. Estimates as determined by static chambers may be improved by increasing the number of gas samples taken and accounting for any non-linearity. In addition, the nitrous oxide emissions respond to soil moisture fluctuations, air temperature fluctuations, and emissions from mineral fertilizers depend on the time of application and the composition of the fertilizer.

Secondly, there is the issue of local produce. The primary method utilized by Weber (2008) was an input−output life-cycle assessment (IO-LCA). This LCA is based on a series of complicated mathematical matrices, such as the industry by commodity matrix and the Leontif inverse, the details of which cannot be fully explained in this synthesis but are gone over in detail in the study. This LCA method is ideal for analysis of large groups of products and for reducing cutoff error. Data on food consumption by households were taken from two main sources: the benchmark U.S. input−output accounts for total economy-wide household expenditure on food and food availability statistics from the U.S. Department of Agriculture for household caloric consumption of food. By using these averages, the study was able to calculate the impact of not only the average food-miles of the produce itself, but also the impacts of the tools needed on the farm, such as tractors etc. However, this study did not have the ability to measure the average distance a consumer must travel to purchase produce (Weber 2008).

<u>Data</u>

Cumulate emission rates varied greatly among different crops during the individual vegetable crop-growing season. N2O emissions from the annual rotation were estimated at 12.0kg N2O-Nha−1year−1 (ranging from 11.4 to 12.8 kg N2O-N ha−1 year−1), of which 49 percent was released during the celery growing season, 24 percent during the lettuce growing season, 11 percent during the radish growing season, and 8.5 percent and 8.0 percent during the first and second Chinese cabbage growing season, respectively (Xiong 2006). Many of the discrepancies of emissions can be associated with the length of the vegetable growing season. The ratio of N2O emission to applied Nitrogen based fertilizer was higher in the treatment with high fertilizer application rate than in the treatment with a low rate. In addition, the specific emissions of N2O resulting from use of urea and manure are higher than those resulting from use of other N-fertilizers (Canals 2006). A correlation between the amount of fertilizer used and the amount of nitrous oxide emissions was found; a reduction by 50 percent N-fertilizer application resulted in 5 to 27 percent less N2O emissions with an average of 16 percent less emissions (Grant 2004). An experiment that compared the different kinds of soil and their associated emissions concluded that the greatest potential to reduce the net GGEs was incorporating permanent grassland, reduced tillage, and elimination of fallow crop lands in a rotation (Grant 2004). Finally, when comparing organic and conventional production systems, it was found that nitrous oxide emissions were similar or higher from conventional than from organic rotations, and 1.6 percent of Nitrogen inputs were lost as nitrous oxide (Petersen 2006). In addition, average soil NH4+ and NO3− concentrations across the monitoring periods were consistently higher for conventional systems compared with the organic systems (Petersen 2006). As far as the impacts of local food and trucked-in foods, it was found using the IO-LCA model that the total supply chain freight transportation accounted for 18 percent of impacts of both fruits and vegetables (Weber 2008). The relationship between carbon dioxide emissions and the locality of produce seems to be linear and easily discernible.

Analysis

Clearly N2O emissions from fruit and vegetable production are quite significant. Accountable factors for contributions to such emissions are primarily the amount of nitrate fertilizers used. The use of manure and urea, i.e. using cow manure to fertilize crops, contributes more to emissions than do mineral enriched nitrate fertilizers. There is a positive correlation between the amount of fertilizers used and the amount of nitrous oxide emitted from the crops, and it is most likely due to these factors that organic farms are more nitrous oxide efficient than their conventional farm counterparts. However, N2O is produced in soils mainly by the bacterial processes of nitrification and denitrification after the application of nitrogen fertilizer as well as chemo-denitrification and fungal transformations; but the specifics of these processes are not well known. Other agricultural practices such as tillage versus no-tillage farms can greatly impact the emissions as well, and the emissions also change with many variables such as weather, time of fertilizer use, temperature and moisture. Local produce is especially important when dealing with fresh, out-of-season produce.

For adoption into campus dining policy, there is much that needs to be researched. There is little information that links particular fruits or vegetables with higher levels of nitrous oxide emissions. In addition, much of the variables of nitrous oxide emissions are dependent on the particular methods used by farms (i.e. tilling practices, fertilizers, etc.) which will be difficult to incorporate into campus dining policy. Organic farms have been shown to be averagely better than conventional farms, but these measurements have shown to be marginally different. In conclusion, an ideal produce system, in terms of GGEs, would use little nitrate fertilizers enriched with minerals, a no tillage system, and would be local. The primary areas that must be further researched are the intricacies of the plants root respiration processes and the determination of the variations of emissions. Because the emissions of nitrous oxide can deviate so much on the day-to-day measurements, it would be fruitful to get some quantitative data on the relationship between nitrous oxide emissions and variables such as temperature and moisture. Without such data for produce, a rating system based on climate foodprints for instance, would be incomplete.

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Grains

Introduction

This literature review discusses the current state of research on GGEs (carbon dioxide, methane and nitrous oxide) from rice, wheat and corn production in the U.S. through life cycle assessment (LCA) and field emissions studies because these studies are crucial for the development of food emissions guidelines for consumers interested in a low-emissions diet. Key issues discussed are; (1) making meaningful comparisons based on emissions between rice, wheat and corn; (2) limited US LCA and field emissions data on rice, wheat and corn products; and, (3) comparing the relative emissions of these crops produced organically vs. conventionally.

Determining the relative emissions of rice, wheat and corn production requires establishing consistent, standardized functional units for emissions, such as kilograms of CO2-equivalents emitted per kilogram of crop produced. These units must be obtained by using consistent and accurate measuring devices, methods and data so that direct comparisons between different types of foods (such as rice, wheat and corn) can be justified. Finally, for these food emissions values to be informative to consumers interested in a low-emissions diet, this data must be made available to consumers in a format that is easily understandable (i.e. a relatively simple, practical unit with origins that are made as transparent as possible). A brief exploration of the general theory, methods, data and analysis of some examples of current research on emissions from rice, wheat and corn production will demonstrate how the complexity of quantifying food emissions currently confounds efforts to create clear, reliable guidelines for a low-emissions diet.

Emissions from Rice Production

Three articles on emissions from rice production are discussed here - one field emissions study, (article 3r), and two LCA studies, (articles 2r and 1r). Article 1r is a PowerPoint presentation of a LCA on rice production in California. Article 2r is a LCA case study of milled rice in the Pijit province in Thailand. Article 3r investigates the effects of applying different amounts of different forms of nitrogen fertilizer on methane and nitrous oxide field emissions from rice plots at the Experimental Farm of Jiangsu Academy of Agricultural Sciences (China) in 1994.

The methods employed in field emissions studies like the one in article 3r are highly complex and technical. Essentially, field emissions were measured by collecting periodic gas samples from a representative rice plot using static flux chambers. The mean methane flux for the plots in which 300 kg N ha-1 in the form of urea and ammonium sulphate were applied were given as 2.85 mg CH4 m-2 h-1 and 1.34 mg CH4 m-2 h-1 respectively. The mean nitrous oxide fluxes for the plots in which 300 kg N ha-1 was applied in the form of urea and ammonium sulphate were given as 23.0 + 9.9 micrograms of N2O m-2 h-1 and 36.5 + 28.7 micrograms of N2O m-2 h-1 respectively. This data is not representative of the emissions from producing all varieties of rice under all types of management in all locations and climates and it therefore cannot be applied directly to developing emissions factors for rice products.

According to the LCA in article 2r, the global warming potential of producing 1 kg of milled rice at this mill in Thailand is 2.9269x103 g (2.9269 kg) of CO_2-equivalents per kilogram of milled rice. The authors commented on their results:

> "In this study, 95% of the global warming inputs to the system are associated with the cultivation process, 2% with the harvesting process and 2% with the seeding and milling processes…The impact during cultivation is largely due to methane emission from rice paddy, 43% of the global warming potential."

It is typical for field emissions data to play a decisive role in the outcome of LCA's. Therefore, data from LCA studies is limited by the reliability and applicability of the field emissions studies upon which they are based. Article 2r also states:

> "There were some data such as fertilizers and chemicals manufacturing that were impossible to be collected, therefore they were cited from some international databases such as…SimaPro software program."

Many LCA studies rely on data from databases and emissions-calculating programs and algorithms, which are also based on field emissions studies to a significant extent. For example, the types of sources that article 1r relied on are typical of LCA studies:

> "UC Davis 2007 Rice Cost of Production Study…Interviews with industry representatives and cooperative extension staff…Published studies from California and Northern China…and the EMFAC, OFFROAD, GREET, US EPA, and Ecoinvent v.2 accessed via SimaPro 7.1 databases."

Typically, primary data for the site being studied is unavailable and this is why many studies rely on these types of non site-specific sources. Significant assumptions are made to apply data from these sources to specific contexts, such as rice production in California.

Article 1r offers two values for emissions from California rice production: 1.93 kg CO_2-equivalents per kg milled rice with 8.96 tons per hectare yield, and 2.83 kg CO_2-equivalents per kg milled rice with 6.12 tons per hectare yield. It also presents emissions values from other studies, along with an emissions value for 1 kg of corn for comparison, as follows: 2.9 kg CO_2-equivalents per kg white rice in northern Italy, 4.24 kg of CO_2-equivalents per kg of milled organic brown rice in California using the economic-input-output to LCA's, and for corn, 0.435 kg of CO_2-equivalents per kg of corn for "production only."

Article 1r presents emissions based on crop yield, which is not directly comparable to the typical units presented in most LCA studies, which usually omit yield specifications. The units presented in Article 3r, the field emissions study, were also not directly comparable to the typical LCA functional unit and it is not clear how data such as the data in article 3r are applied in LCA studies. The data from article 2r was not intended to be applied to a U.S. context, but it is illustrative of the type of data that is required for U.S. rice, which is currently very limited. In any case, the kind of emissions data presented in these articles is not yet reliable enough or clear enough to be used to establish clear emissions guidelines for rice consumption.

Emissions from Corn Production

Two articles on emissions from corn production are considered here. Article 1c was a field emissions study, "conducted in four treatments of the Ecological Intensification of Irrigated Maize-based Cropping Systems Experiment at the University of Nebraska-Lincoln East Campus in Lincoln, NE…in 1999." Article 2r is a corn LCA that attempts, "to estimate the county-level environmental performance for continuous corn cultivation of corn grain and corn stover [the corn plant, aside from the corn grain] in various corn-growing locations in the [US] Corn Belt States.

In the study in article 1c, static flux chambers, similar to the ones used in the rice field emissions study, were used. "Grain yields of maize…and soybean…as well as crop nitrogen and carbon uptake were determined from a harvest area of two rows x 9 m in each plot…Average annual emissions of carbon dioxide, nitrous oxides and methane measured at the soil surface for one complete crop rotation cycle (2004-2005) were…"

1) 5612 kg CO2-C ha-1 yr-1, 1.87 kg N2O-N ha-1 yr-1 and -3.36 kg CH4-C ha-1 yr-1 for CC- rec (continuous corn under recommended practices)

2) 5779 kg CO2-C ha-1 yr-1, 2.16 kg N2O-N ha-1 yr-1 and -3.13 kg CH4-C ha-1 yr-1 for CC-int (continuous corn under intensive management practices)

The emissions data in article 1c were presented in another unfamiliar type of unit – not in CO2-equivalents, or micrograms m-2 h-1, but in kilograms of three different types of emissions (CO2, N2O and CH4), ha-1 yr-1 for two different types of management systems for the same type of crop. Article 1e also raises concern about generalizing the results from such a small scale experiment (2 rows by 9 meters) to U.S. corn field emissions in general. This was probably not intended by the authors, who were concerned primarily with comparing the relative emissions of intensive and recommended farming practices, rather than presenting field emissions data for corn production in general. When considering the findings of a similar study, article 1c points out that:

> "At similar levels of fertilizer-N input, both soil NO3-N and N2O fluxes in our study were nearly a magnitude lower than those reported in their study…the major difference between these two studies lies in the general level of crop management and the crop yields, which in our experiment were about twice as high than those reported by McSwiney and Robertons (2005)."

Also:

> "…the standard errors of the cumulative changes in SOC [soil organic carbon] measured for the 2000-2005 period were relatively large (+ 60-130 g C m-2)…More experimental years will be needed…Positive or negative changes in

> SOC, intrinsic carbon costs associated with crop production and soil nitrous oxide emissions were major contributors to the net GWP."

In many LCA's, using data that is not site-specific is currently a prevalent problem. Article 2 helped demonstrate the significance of regional variations of emissions from crop production. Article 2r states:

> "For each county, field emissions (sum of carbon sequestration and N2O emissions from soil) are the most significant contributor to total greenhouse gas emissions…The local variations of greenhouse gas emissions associated with corn grain are even larger because of local differences in nitrogen fertilizer application, soil properties, and climate conditions."

With respect to fertilizer application rates and location specific data, article 2r states:

> "The nitrogen fertilizer application rate significantly affects the environmental performance of producing corn grain…Over 30% of the total fossil energy associated with corn grain…comes from nitrogen fertilizer. N2O emitted from the soil is the dominant greenhouse gas, which is associated with nitrogen fertilizer… Since nitrogen fertilizer has such a large effect on the corn-farming LCA results, it is important to have the most accurate input data on fertilizer use as possible. If county-level data were to become available, the state-level data used in this study should be validated…In general, county-level modeling is more accurate…When possible, site specific experimental information on yield, erosion, soil carbon, and nitrogen dynamics should be obtained to reflect the system more accurately. The gathering of site-specific agronomic data is a general difficulty in modeling any bio-based process and further research in this area and field-scale testing is recommended."

In the LCA study in article 2c, "Eight counties in seven different states…are studied…Hardin County (IA), Fulton County (IL), Tuscola County (MI), Morrison County (MN), Freeborn County (MN), Macon County (MO), Hamilton County (NE), and Codington County (SD)." And, "…state level values are used in the agronomic inputs and fuel consumption instead of county-level values due to lack of county-level information…"

According to this study, the emissions incurred in the production of corn, given in grams of CO2-eq. per kilogram of corn are: 254 in Hardin County (IA), 389 in Fulton County (IL), 401 in Tuscola County (MI), 442 in Morrison County (MN), 416 in Freeborn County (MN), 825 in Macon County (MO), 370 in Hamilton County (NE), and 289 in Codington County (SD). Overall, "Greenhouse gas emissions associated with corn grain production are 254 to 825 g CO2-eq. kg-1 of dry corn grain."

As demonstrated earlier, these emissions values are based on many assumptions and they are not yet reliable enough to be used on developing food emissions guidelines, though they take food emissions data in a progressive direction - towards being location-specific.

Emissions from Wheat Production

Two articles on emissions from wheat production are discussed here. Article 1w is a LCA of four types of US wheat; (1) Hard Red Winter produced in Montana, Kansas and Oklahoma; (2) Hard Red Spring produced in Minnesota, Montana and North Dakota; (3) Soft Red Winter produced in Ohio, Illinois and Missouri; and (4), Soft White Winter produced in Idaho, Washington and Oregon. Article 2w is a streamlined, hybrid EIO (Economic Input-Output) LCA study comparing the GGEs of production of organic vs. conventional wheat in the US.

According to article 1w, grams of CO2-eq for the production of 1 kg of dry Hard Red Winter wheat in Montana, Kansas and Oklahoma are 136, 251 and 316. For Hard Red Spring wheat in Minnesota, Montana and North Dakota the values are 202, 233 and 272. For Soft Red Winter wheat in Ohio, Illinois and Missouri the values are 146, 180 and 219. For Soft White Winter in Idaho, Washington and Oregon the values are 152, 160 and 178. This study also states that:

> "…Intra-species variation for greenhouse gas emissions is as large as 101% for Hard Red Winter and as little as 7% for Soft White Winter…Generally, harder wheat has larger fertilizer application (Hard Red Winter)…which increase greenhouse gas emissions."

Article 1w cautions that:

> "Agricultural practices, including resource use and emissions, vary widely by location and individual species, even for the same variety of nutrients, precipitation, and temperature (Fernandez-Cornejo and Jans, 1999). For example, fertilizer and other agro-chemical application, which constitute one of the largest relative contributions to greenhouse gas and toxic emissions, can vary by over 300% by location for the same crop…The amount of carbon sequestered is highly variable and dependent on location and farming practices…the variability and disagreement in studies of wheat's potential to sequester carbon cannot be understated…Small variations in carbon sequestration by field location…have the potential for an order of magnitude variation in greenhouse gas emissions."

Article 1w presents different emissions data for multiple species of a crop - wheat in this case. Article 1w sheds light on the fact that much of the LCA studies (or even field emission studies) discussed earlier may be severely confounded if they did not account for the species of the crop being studied.

According to article 2w, "the GWP of producing 0.67 kg of conventional wheat flour (for a 1 kg bread loaf), not including product transport or various omitted processes, is 190 g CO2-eq, while the GWP of producing the [equivalent amount of] wheat organically is 160 g CO2-eq." An important caveat of this study is that:

> "Since we employ a streamlined method, our cut-off criteria are processes that are similar for conventional and organic bread production. These processes include

> wheat milling, bread baking, packaging, and local distribution and procurement [there were also other processes that were cut out from this analysis]. Anderson and Ohlsson report that food processing can contribute up to one third of total impacts from the conventional wheat bread life cycle. However, since the aforementioned processes are the same for organic and conventional wheat bread, omitting them does not affect…GWP differences between the two systems."

Therefore, these emissions values are low, since many production processes are omitted. The study assumes that, "Although nutrient sources are different for conventional and organic grain farming, it was assumed that nutrient requirements per kg of harvested wheat are the same for both systems." Numerous differences between organic and conventional wheat production are accounted for. For example, "For the organic wheat system, nitrogen is applied via leguminous cover crops, and may be augmented with manure." Further details are as follows:

> "In our analysis, GHG emissions from manure storage and composting are assigned to the organic wheat production system…Machinery manufacturing impacts are assigned to be the same for both systems…For conventional agriculture, the production and transport of conventional pesticides are considered…Organic farms primarily plow or till as a mechanical method of controlling weeds, instead of using herbicides...For this study, we assume that organic yields are 75% of the conventional yields…Conventional wheat yield used in this study is 2.8 t grain ha-1 (42 bushel acre-1). This is the US average from 9 years (1997-2005), as reported by USDA databases. This study considered generic wheat and made no distinction between winter wheat and spring wheat….It was assumed that organic and conventional wheat production consume the same amount of liquid fuel and use farm equipment at the same rate per hectare...For this analysis, organic and conventional wheat are supplied the same amount of nitrogen per kg of wheat produced…we assume that N2O emissions amount to 1.3% of total nitrogen supply for both systems…Due to…numerous uncertainties, we assume…that soil carbon storage potential is the same for both systems."

The authors acknowledge that:

> "It is important to note that farms (both conventional and organic) might not harvest the same crop every year, or every season. Rotations with other crops can increase soil quality and reduce nitrogen fertilizer requirements in crop production. It is acknowledged that organic wheat production may require different crop rotations than conventional production, and there may be more wheat harvests in conventional production than organic…In this analysis, it was assumed that during wheat off-seasons, the alternative crops grown have equivalent economic value in the two systems. Therefore, the yields considered are for the season during which wheat is grown…Since studies of organic wheat yield in the US are limited, organic yield is a key parameter in this assessment."

But the organic yield used in this study was merely an estimation based on limited data. Some general conclusions drawn from this study are:

> "…the geographic origin of one's food alone is not necessarily the most important…Farming practices…matter greatly when discussing the difference between organic and conventional products…This underscores the important role of best farming and transport practices..."

The difference in emissions reported by this article, (160 g CO2-eq kg-1 organic vs. 190 g CO2-eq kg-1 conventional) is relatively small, small enough to be fairly insignificant. Also, these results are called into question by the results presented in article 1r, which suggest the opposite trend - that the emissions for production of organic brown rice is presented as potentially higher than emissions for production of conventionally produced white rice, (4.24 kg CO2-eq kg-1 milled organic brown rice with unspecified yield vs. 1.93 kg CO2-equivalents per kg milled rice with 8.96 tons per hectare yield and 2.83 kg CO2-equivalents per kg milled rice with 6.12 tons per hectare yield).

In summation, the data from this organic vs. conventional wheat emissions study and most other emissions studies is inconclusive since there are still too many possible and significant sources of error, such as omitted processes, field emissions, and different wheat species, climates and locations that were not accounted for and may easily confound a study's results.

Conclusion

Developing easily comprehensible, scientifically justifiable guidelines for the relative GGEs of rice, corn and wheat - especially when considering whether or not these crops are produced organic or conventionally - for food consumers interested in a low-emissions diet is a task that may be exceedingly difficult using the type of research and data considered in this literature review at its current state. Possibly there is enough data to categorize rice, wheat and corn in a generalized sense, as in comparing these crops to other types of food such as poultry or highly processed foods, but this would have to be done with great caution.

Key goals of future research in this area for the purpose of developing food emissions guidelines for consumers may be; (1) definitively establishing reliable ways to quantify field emissions; (2) generating primary, location-specific LCA inventory data for rice, wheat and corn production in the US; (3) developing more robust and reliable methods of data collection and development, such as real-time emissions monitoring equipment designed specifically for large scale agriculture (methods superior to small scale experiments coupled with reliance on limited, generalized databases that make multiple assumptions); and, (4) developing standardized, compatible and comparable units.

Ultimately, these units must be comprehensible to food consumers. Possibly the LCA unit of CO2-equivalents per kg of food product will become the standard unit used in developing relative food emissions guidelines for food consumers, since it may be more easily understood than some of the other units presented in these types of articles.

Unfortunately, it may be that food consumers cannot be expected to understand how these emissions units are developed, since the means of obtaining these units are so complex.

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Policy Recommendations

Beef

1. Amount of beef purchased should be lowered; beef can be replaced with poultry or pork (poultry is probably a better idea due to cultural and/or religious limits on pork consumption)
2. Beef purchased should ideally be grass-fed regardless of whether farm is local (but local is preferable)
3. If beef is being purchased from a CAFO, ideally the farm should be actively trying to lower their GGEs.
    - There are currently systems and new technologies that can be used to reduce emissions associated with manure/waste, like using animal waste to create biofuels.
    - This recommendation can be applied to poultry and pork as well.
4. The UC system should encourage further research and efforts to attempt to better understand the relation between food production and GGEs within California and the United States

Poultry

1. One can lessen their own contributions to GGEs by replacing red meat with poultry.
2. While poultry production may be less emissions intensive than other livestock systems, it is important to consider the fact that the poultry production system is still far more emissions intensive than fruit and vegetable production.
3. In order to lessen one's own "climate foodprint", the best dietary option is one with limited meat intake, eating mainly vegetables and legumes as a protein source, while only occasionally eating meat.

Dairy

1. The UC should make a point to conduct more research about the vendors from whom they are procuring dairy products. Buying from a conventional farm that is currently taking steps to reduce their GGEs could be the best option because organic farms do not always have the lowest emission rates per amount of yield.
2. The UC dining commons as a whole should practice going lacto-ovo free for one or more days a quarter. There is a large amount of emissions related to dairy consumption and the easiest way to decrease emission rates would be to cut it out of the diet.
3. The UC admin and dining commons should look into soy products that could replace dairy. Soy products might be a great alternative that could help reduce emission rates.

Produce

1. Special attention should be paid to produce that is out-of-season, as this is the produce that travels the farthest post-production distance.
2. It would be important to gather information of farms when purchasing produce, such as fertilizer usage and soil management practices, and choosing to do business with those farms that use small amounts of nitrite fertilizers and no-tillage soil management. Organic farms very often employ these best practices.

Grains

1. Purchase rice with a low moisture content, since it requires less energy for cooking. (Cooking accounts for a significant percentage of the energy of rice's life cycle).
2. Although corn is relatively low in emissions, organic varieties are most likely best.
3. Life-cycle assessments suggest that soft white wheat has the lowest emissions of any variety of wheat.
4. In general, have an idea of whether or not supplying farms use best practices for crop cultivation, since this is essential for minimizing crop production emissions.