ABSTRACT

BALCAZAR TELLEZ, MARIA FERNANDA. Sustainability: From Food Security to Renewable Energy Production. (Under the direction of Dr. John J. Classen.)

Sustainable development plays a key role in agriculture, food production and security. The goal of this thesis is to explore the complexities of sustainable development as a concept in action. More specifically, sustainable development in agriculture and food production is explored in both a global scale—determining which factors affect food production and security—and in a local setting by utilizing agricultural waste as a renewable energy resource to generate bio-methane. Using path analysis techniques and global and national explanations sustainability outcomes are examined for 218 nations during the modern period. Results indicate that strong direct or indirect links exist between global geography, global power and national capitals, as well as warfare and military expenditures, and economic development. In turn these factors are differentially predictive of other key measures of sustainability such as food sources, including cereals and meat, which relate to food security and threats to the environment. Results highlight the importance of approaching complex global challenges, such as limited food security or increased food production, from a global big-picture perspective to achieve successfully global goals. On the other hand, anaerobic digestion was evaluated as a sustainable waste management alternative in swine farms in North Carolina. Concentrated swine farm operations produce sizeable amounts of manure, which are commonly treated using anaerobic lagoons which have been associated with several adverse environmental and health problems. The recent introduction of a separation system, known as a scraper, allows for the collection of manure without added water either as scraped solids (SS) and scraped liquids or as whole slurry (WS). A biochemical methane potential (BMP) test was conducted to determine the methane potential of these two substrates, at three different temperatures of 63°C, 35°C, and 25°C. One-way ANOVA tests determined there was no statistical significant difference among WS and SS, for all tested temperatures. While not significantly different, greater methane production potential was observed under the WS-25°C treatment; this was attributed to acclimatization of this treatment, in addition to higher VS content and waste volume. However, to create a cost-effective and efficient waste management option the combination of waste volume and VS content needs to considered, as digester volume capacity is directly related to implementation costs. The smaller reactor intended for SS digestion is

likely to have significant lower costs than a reactor designed to digest WS waste volumes; this in turn would provide greater opportunities for adoption in the swine industry. The results of this thesis point to the need to address environmental and engineering challenges from a macro-perspective to generate solutions and alternatives that are truly sustainable and accessible.

Sustainability: From Food Security to Renewable Energy Production

by
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DEDICATION

I dedicate this work to my country, Venezuela and offer it as a *brindis* to all my fellow Venezuelans students and immigrants. Venezuela, the country that brought me to be strong, determined and endlessly gave me good humor, jokes and loud, friendly chatter and laughter over some good *salsa*. In many ways, that was the biggest gift that supported since day one of my studies abroad. To all students, from all walks of life, who have emigrated or remained. No matter their choice, both hardship and hope have taught us that there is more to give than to loose, more to learn and more to share.

May we soak in all this diversity, may we overcome adversity,
may we learn new and sustainable ways; may we always remember our roots.
May we gather the seeds or knowledge, passion, wisdom, and compassion,
and may we plant them close to home.

To my family, all those amazing friends, and fellow Venezuelans who have scattered throughout this planet… this one is for you!

This work is also dedicated to all of the amazing human beings, from countless corners of the planet, who have been kind to show me their world. I am incredibly blessed to have been able to lean on you, learn with you, and grow together. You are family, and you have offered me a wonderful home away from home. This one, this one is for you too!

BIOGRAPHY

Maria was born and raised in Caracas, Venezuela. According to reliable sources, the third word she first said when she was little was *cambur*, which is what Venezuelans call banana. *Agua*, which translates to water, came as number one. Maybe that was a coincidence, or maybe it was the beginning of her keen interest in environmental concerns and food production. Seventeen years later she joined the Pennsylvania State University where she completed a double major in Biological and Agricultural Engineering and Philosophy, with a minor in Environmental Engineering. Research in sustainable food production and food access, as it relates to the world from both an environmental and sociological perspective, started sparking as an interest during her undergraduate studies. That interest brought her to complete a master degree in North Carolina State University, under the guidance of Dr. John J. Classen, in Fall of 2014. She has dedicated two years to study food security issues at a global scale and renewable biogas production using anaerobic digestion technology. After completing her Master's degree, she plans to continue her graduate education by pursuing a Ph.D. degree in the field of sociology or public policy, with a focus on food security and energy production.

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CHAPTER 1: Literature Review

1. Sustainability as it Relates to Agriculture and Food Production

Sustainability has gained popularity as a term, however as to how it is specifically defined is still up for lively debate (Morelli, 2011). Introduced by the UN Bruntland commission, sustainable development is popularly defined as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commision of Environment and Development, 1987). The struggle to define sustainability relates to the differences in opinion as to what needs to be included. Some argue that economic development must be part of the equation, in addition to society and environment. This definition has gained popularity in the business world, and was introduced by John Elkington in 1994 as the triple bottom line (Hindle, 2008). This 'thin version' of the sustainability definition, aims to reconcile economic growth and protection of the environment (Morelli, 2011). It highlights the importance of sustainability offering a "win-win" scenario, popular in the business world (Mebratu, 1998; Morelli, 2011; Toman, 1992; Vos, 2007). Others argue that sustainability is a simple relationship between society and the environment, aiming to give the definition an openness to personal political and philosophical interpretation (Robinson, 2004). The Food and Agricultural Organization's (FAO) definition includes the economic component, and defines sustainable development as environmentally maintainable, economically viable, and socially acceptable (FAO, 1998). Sustainable development plays a key role in agriculture, food production and security.

The goal of this thesis is to explore the complexities of sustainable development as a concept in action. More specifically, sustainable development in agriculture and food production is explored in both a global scale, by performing a cross-country analysis to determine how various factors affect food security, as well as in a more specific local setting with an agricultural engineering challenge faced in the swine industry in North Carolina.

In order to unravel the complexities of sustainable development social theories of international development are introduced in the discussion. These theories give an opportunity to understand the complexity of the modern world, and offer the context where food production and agriculture operates.

1.1. Development Theories and Examinations of Hunger and Agriculture

1.1.1. Modernization Theory of Economic and Social Development

Modernization theory refers to a model of progressive transition of traditional –or "pre-modern"—human values, technology, culture to a modern one. Typically, Western nations are recognized as developed nations and as blue-prints for how developing nations should proceed in order to develop modern economies, modern values and work ethics and superior technologies (Inkeles, 1975; Rostow, 1960). According to the theory, a combination of cultural and natural factors is what allows some nations to achieve a greater degree of modernization in comparison to others; this can be observed in socially and economically developed nations (Rostow, 1960). Thus, classical modernization theory considers social change to be linear, progressing from a pre-modern to a modern and homogeneous nation that, ideally, follows the Western society configuration (Comte, 1824; Durkheim, 1984; Parsons, 1964). However, these classical modernization theories have been criticized for assuming traditional values as inferior, assuming unidirectional forms of development, and being ethnocentric in nature.

Modernization theories of development today have stressed a removed position of the state and the rule of a free market. Such neoliberal theories of development aim at promoting developing nations by introducing unrestrained and integrated global trade, and limited governmental intervention to the economic infrastructure and regulatory framework (Appelbaum & Robinson, 2005; Chase-Dunn, 2006; Krugman, 1999).

Historically, the modernization model has been implemented in agricultural development as a strategy for national development. It drove the Green Revolution with the introduction of mechanization, synthetic fertilizer, hybridized seeds, and industrializing production in agriculture in developing nations (Carolan, 2012). This approach was based on the notion that increased food availability could be only achieved through technological adoption and innovation, and indeed cereal production more than doubled in developing nations between 1961 and 1985 (Conway, 1998). As production increased, it was expected that demand would potentially increase, increasing national economic development, and therefore achieving infrastructure and rural income modernization (Lipton, 1975). According to the World Bank, this theoretical approach to agricultural production and trade in global markets is a clear path to economic prosperity (World Bank, 2007).

However, critics suggest that although we observe food surplus and increased international trade, lack of food security persists in less developed countries. A cross-country analysis done by Jenkins & Scanlan (2001) found a relatively weak impact of food supply on child hunger rates. Other factors, such as political inequality, internal violence against minorities and other groups, social stratification and military power were found to be fundamental to child hunger, making lack of food security a both political and distributional problem (Jenkins et al., 2007; Jenkins & Scanlan, 2001; Scanlan, 2001). Comparably, Brady et al. (2007) found that, over time, economic development—in terms of GDP per capita—of a nation has become much less effective at improving caloric consumption and infant survival in less developed nations than gross domestic product. Their conclusions point out the serious limitations to solely concentrating on economic growth to improve well-being in less developed countries (Brady et al., 2007). On the other hand, Firebaugh (1996) determined economic integration, through foreign capital penetration, to result in higher productivity and household incomes, which in turn, he suggests increases purchasing power and encourages caloric consumption . Similarly, Fan & Rosegrant (2008) observed that increases in agricultural productivity have enabled many to escape from food starvation, particularly in Europe, Asia and parts of Latin America.

Thus, while research is yet not conclusive, variables such as agricultural production, food access, gross domestic product, infrastructure, local resources, and education are among some of the important variables to consider when discussing global food security, and sustainable development. Chapter 2 aims to address how these variables relate to food security, environmental degradation, and economic development.

1.1.2. Dependency Theory and World-Systems Theories of Social and Economic Development

Dependency theory is defined as the understanding that the economic development of a nation is greatly dependent upon external political, economic and cultural influences, which in turn affect national development policies (Sunkel, 1969). This theory originates from various conflicting theories on social change and development that had been thus far influenced by classical scholar theory of Marx (1867), Kautsky (1899) and Lenin (1917). Under dependency theory principles valuable resources flow from poorer nations—known to be in the peripheral zone—to wealthier ones, known as core nations, resulting in unjust trading relationships and access to the global economy (Amin, 1976; Frank, 1966). Wallerstein (1974) developed this theory further by introducing a three-tier system on which the world system was composed of core, semi-peripheral, and peripheral countries. Development theory explains how economic and social development of core countries have an advantage over semi-peripheral and peripheral-nation states, as cheap labor and raw materials from the latter allow core nations to profit from surplus value (Amin, 1976; Frank, 1966; Wallerstein, 1974). Consequently, peripheral-nation states are in disadvantage to promote development from within through taxation and domestic savings, which reduces the amount of investment that could otherwise go into development, social welfare, resulting in various social problems (Chase-Dunn, 1989).

Production and availability of food are not the only driving factors of limited food security and global hunger. In order to effectively address food insecurity and hunger we need to understand the global and local context in which food production and access operates.

Understanding how food production and food distribution relate to food insecurity and global hunger through the historical context, and the discourse that has been adopted are key components to developing new sustainable solutions that address food insecurity.

1.2. Production versus Distribution Debate

As any major introduction of technological innovation, the Green Revolution inevitably introduced change in both the established methods to achieve a goal as well as significant social changes. The Green Revolution is well praised for its significant increase in production, particularly in India, Pakistan and South-East Asia. A report by the FAO (2004) stated that between 1960 and 2000 yields for developing countries increased up to 208% for wheat, 109% for rice, 157% for maize, 78% for potatoes, and 36% for cassava. However, it is important to mention that global aggregates disguise major geographical productivity differences. The Green Revolution agenda in developing nations included, via agricultural industrialization, domestic modernization, higher farmer wages, employment for rural communities, and feeding growing populations (McMichael, 2009; Moritzer, 2008; Thompson, 2012). Limited success was observed, particularly in South Africa, due to limited infrastructure, technological innovation, poor distribution of limited quantities of fertilizer and resources (Machethe, 2004). Similarly, it was observed that Green Revolution strategies included intensification of areas that were originally favorable, leading to much lower results in marginal areas, especially in marginal production environments with major stresses such as drought or flooding (Pingali, 2012).

In regards to social progress, contradictory results were observed with the introduction of the Green Revolution. Many argue that while the Green Revolution significantly increased food production, it also further exacerbated social inequality, particularly in developing nations (Carolan, 2012; De Janvry, 1981; Galli, 1981; Lipton, 1977). Major capital investment was simply unreachable for millions of peasants in poor rural areas in Asia and Africa. The International Rice Research Institute reports that choosing high-yielding varieties of rice instead of traditional seeds increased cultivation costs from $20 to $200 per hectare (Skorov, 1973). This major increase in capital investment gave rise to prosperous farmers and large landowners to expand their operations and account for the majority of the reported yield increase (Carolan, 2012; Lipton, 1977; Skorov, 1973). The unequal opportunities to attain agro-technology has allowed wealthy farmers to increase production, and therefore wealth, while leaving many peasants in impoverished conditions. Additionally, the productionist argument, where global hunger exists as a result of inadequate or declining food production, has proven to be false in its entirety. Famine and hunger have been found to emanate from inadequate access to food, rather than inadequate production (Carolan, 2012; Kick et al. , 2011; Sen, 1981; Thompson, 2012). Additionally, the Green Revolution has been linked to environmental issues such as loss of biodiversity, air pollution due to higher non-renewable energy consumption, water pollution due to fertilizer losses, inequitable asset distribution and worsened absolute poverty (McMichael, 2009; Moritzer, 2008; Skorov, 1973).

It is clear that a major technological shift, such as the Green Revolution, was bound to create a myriad of intended and unintended effects. As we continue our efforts to tackle hunger and food insecurity through sustainable development, integration of social, physical and natural sciences is crucial to understand and take appropriate educated action. Food security and hunger innately operate in a complex, dynamic and diverse environment that intersects fields of engineering, environmental science, political ecology, law, social sciences and economics. Thus, to successfully address the ill-natured food security and hunger challenge interdisciplinary research and collaboration is vital. Additionally, the public and research sectors ought to develop and implement solutions and policies together, giving particular attention to the specifics on local challenges while addressing the global goals. One example of this is an effort at improving the recovery and reuse of resources in food animal production systems, such as swine production in North Carolina. Currently resources of carbon, nitrogen, and phosphorus are either lost to the environment or disposed with little regard to maximizing their value.

In the following section anaerobic digestion technology will be introduced, studied and proposed as an alternative sustainable solution to waste management in the swine industry in NC. The proposal of this technology represents current efforts to introduce sustainable development in the livestock industry, by addressing current waste management concerns and bringing multiple benefits to the farmer, community and environment.

2. Anaerobic Digestion: Sustainable alternative to swine manure waste

2.1. Introduction of the Problem

The global greenhouse gas (GHG) emissions have increased by up to 35% from 1990 to 2010 (EPA, 2014). The sector with the second greatest emissions, with up to 13% contribution in 2010, was agriculture (EPA, 2014). In order to minimize global warming and climate change impacts, GHG emissions must be reduced. These global challenges are to be faced with GHG mitigation, thus implementation of new technologies that are able to address the problem at its source its critical. Additionally, energy demand is rapidly growing. World energy consumption is expected to grow 56% from 2010 and 2040, going from 552,000 quadrillion MJ to 865,100 quadrillion MJ (EIA, 2013).

In this context, biogas production from agricultural wastes and residues shows great potential as part of the solution as it not only produces methane as a form of energy but also collects greenhouse gas emissions which would otherwise be released into the atmosphere. The production of biogas through anaerobic digestion systems has proven to be effective in many European countries, such as Germany and Denmark (Weiland, 2010).

In the United States the swine industry has changed dramatically in the past 20 years, going from a hogs and pigs inventory of 5.5 million in 1982 to 66 million in 2012 (USDA, 1982; USDA, 2012). Higher production has been accomplished by the introduction of confined animal operations. Confinement systems have become popular as they increase animal production with no need to increase operation areas. North Carolina plays a significant role in swine production as the second largest hog producer state in the country (USDA, 2007). However, anaerobic lagoon waste management systems implemented in North Carolina's hog farms have been associated with environmental concerns (Liang et al., 2002; Mallin, 2000; Schiffman et al., 2005; Schinasi et al., 2011; USDA, 2012). Furthermore, these systems lose potential energy in the form of methane as well as nutrients, especially nitrogen in the form of ammonia and phosphorus in the bottom sludge of the lagoon.

As the adoption of Concentrated Animal Feeding Operations (CAFOs) become more widespread, environmental and health issues due to animal food production systems will become a primary concern, especially to individuals that either work in such operations or reside in close proximity to them. The high amount of waste such operations generate on a regular basis and its disposal poses many different environmental challenges, especially to water and air quality (Mallin, 2000; USDA, 2012). Surface and ground water in close proximity to confined animal feeding operations can be at risk, as animal waste contains a number of water contaminants. The primary contaminants found in animal waste that present concerns to water quality are nitrogen and phosphorus (USDA, 2012). Other potential contaminants include sediment, pathogens, heavy metals, hormones, and antibiotics (EPA, 1999). Excess nutrients in water bodies have many different effects. One main concern is the blooms of algae as a direct result of nutrient loading. This is related to low dissolved oxygen levels in water known as anoxia. Anoxia is known to affect fish and invertebrates' health in different ways. In some cases, in combination with other circumstances, nutrient loading has resulted in toxic outbreaks of microbes such as *Pfiesteria piscicida* (Mallin, 2000; EPA, 1999).

Agricultural practices have been linked to a rise in gas emissions. Such gases are related to great environmental concerns. Gases such as ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and sulfur dioxide (SO_2) and nitrous oxide (N_2O) are emitted by common animal agriculture practices. Globally, agriculture is considered to be the most important source of nitrous oxide, with a total value of 68% (Dincer, 2010; Ni et al., 2010). On the other hand, it was determined that animal manure is the largest contributor to atmospheric ammonia emissions in the United States (Battye et al., 1994). Anaerobic lagoons have proven to be a considerable source of ammonia nitrogen emissions. Estimated average yearly emissions of a typical North Carolina swine lagoon are about 2340 kg/ha (Liang et al., 2002). In the United States pork production systems were determined to be the second highest green-house gases emitter in comparison with all other animal food production systems, following beef production (De Vries et al., 2012). Anaerobic lagoons present a particular problem, as they store the manure in a very diluted state. According to Barker (1996) lagoon sludge solids contents range from 6-13%, which in turn requires careful selection of removal equipment. This diluted state represents a problem in terms transportation of high volume of liquid with little solid and nutrient content. Total nitrogen content of liquid slurry swine manure is 3.72 g/L of manure. However, that number significantly drops to 0.59 g N/L of anaerobic lagoon liquid (Crouse et al., n.d.). This represents a low nitrogen content when compared to traditional fertilizers such as anhydrous ammonia-NH_3, Urea-N_2-CO-NH_2, and ammonium nitrate-NH_4NO_3 with 82, 46, and 33% nitrogen content (Penn State Extension, 2016.). The nitrogen content decreases due to, in part to volatilization of nitrogen, as well as some of the nitrogen traveling to the bottom lagoon sludge (Crouse et al., n.d.). Additionally, Ni et al. (2010) determined that as manure dilution increases, so does the total emissions of hydrogen sulfide and sulfur dioxide. Although hydrogen sulfide and sulfur dioxide emissions are not considered greenhouse gases, they are considered pollutants by the EPA and have serious negative environmental and health effects. Anaerobic digestion offers the opportunity to collect these GHG emissions and other emitted pollutants. Most of these collected emissions can be used as a renewable source of energy production, while other air pollutants are collected reducing contaminants in the atmosphere.

CAFOs have also been determined to emit air pollutants linked with many different health concerns. Such pollutants cause acute physical symptoms, especially upper respiratory symptoms and nose and eye irritation (Schinasi et al., 2011). Healthy subjects in contact with swine waste emissions tend to experience headaches, eye irritation and nausea with significantly more frequency than in the absence of such emissions (Schiffman et al., 2005). This is not limited to swine farmers or operators, but also applies to individuals in surrounding neighborhoods. Other recorded symptoms include excessive coughing, diarrhea, runny nose, sore throat and burning eyes in addition to the common headache (Wing et al., 2000).

In order to address all these different issues and concerns, new systems for waste management have been the topic of research. Anaerobic digestion is in many ways ideal for animal waste management systems, as animal feeding operations provide animal manure on regular basis. Manure collected in North Carolina swine farm operations are particularly relevant, as currently used waste management systems have major environmental and health impacts to surrounding communities. Anaerobic digestion is one of the alternatives that has shown to be most responsive to the issues at hand in addition to providing a steady source of renewable energy.

2.2. Anaerobic digestion: System Overview

Biogas is produced as a result of anaerobically digested organic waste materials. A consortium of facultative and anaerobic bacteria is responsible for the complex metabolic processes that covert organic compounds into biogas (Cheng, 2010). Biogas is largely composed of methane and carbon dioxide, with small amounts of nitrogen, hydrogen, ammonia and oxygen. Methane, which accounts for 50-80% of the biogas, is the combustible component of the products. When burned it produces water, carbon dioxide and heat (Cheng, 2010). The exact composition of biogas is highly dependent upon the feedstock. Factors to consider include the waste composition, reactor design, mixing and feeding regime, as well as the retention time (Gontupil, 2013; Weiland, 2010).

Anaerobic digestion paired with a scraper system could provide a cost-effective solution that addresses many of the challenges observed with current swine lagoon management systems. The scraper system is able to collect waste on regular basis (typically 24-hour periods), thus it provides a steady source of waste that could be introduce to continuous anaerobic digesters. Additionally, scraper systems have also been shown to greatly reduce loss of readily digestable and organic materials, which in turn increases biogas production

(Vanderholm et al., 2009). Also, the scraper substitutes the use of a pump by allowing waste to drain continuously, and to be removed via the scraper system. Some have the capacity to collect drained liquids in a separate storage; when the scraper operates twice per day, a cover diverts the collected solids to a separate collection tank. This allows the waste collection of separated solids and separated liquids, while other scrapers allow the collection of the whole slurry. Scrapers can be retrofitted in most NC hog farms, as long as it has an underfloor manure collection system. Furthermore, some scraper systems address the swine waste dilution challenge observed in anaerobic lagoons by separating the solids part from the liquids. If implemented, solids separation is likely to result in reduced transportation costs for the farmer of swine manure higher in solids and nutrients. Lastly, the liquid portion, expected to be higher in nutrients, could potentially be paired with other technologies—such as a permeable membrane—in order to create an additional revenue stream for farm operators.

2.2.1. Stages

The anaerobic digestion is a complex process that requires a combination of various bacteria in order to achieve the following four successive stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Cheng, 2010). Figure 1 displays a schematic diagram of the process of this process.

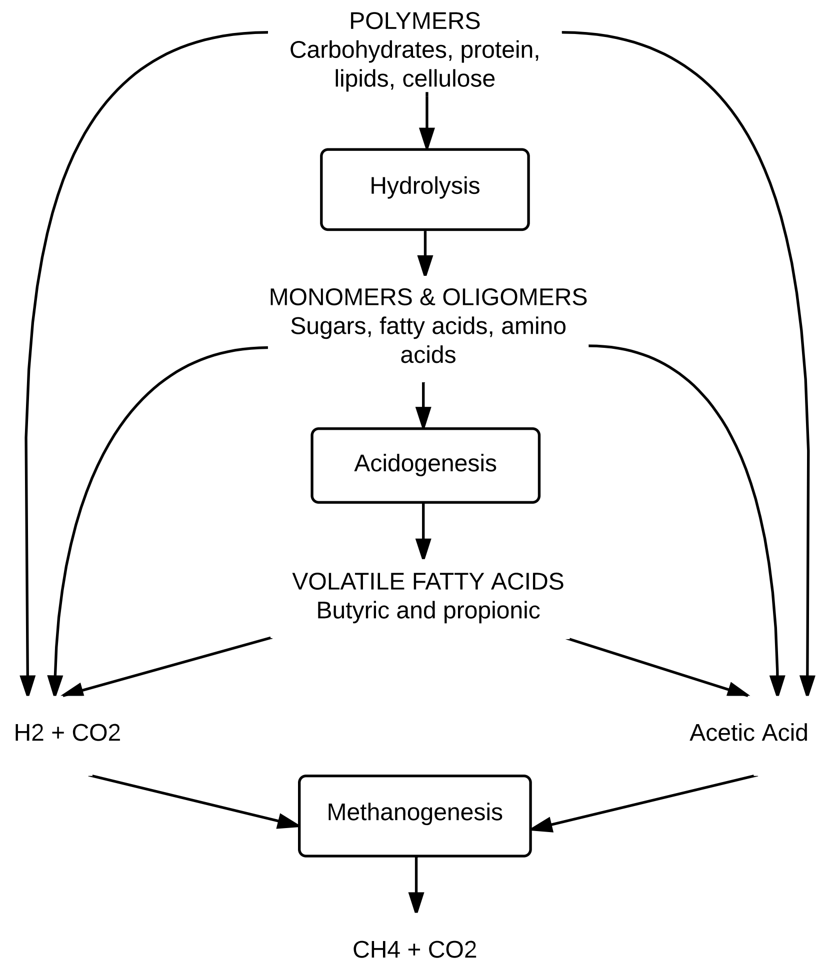

Figure 1. Scheme of Anaerobic Digestion Process (Adapted from Cheng, 2010)

Hydrolysis: In this phase organic waste materials of high molecular weight—known as polymers—such as carbohydrates, proteins, lipids, and celluloses, are hydrolyzed by anaerobic bacteria (both facultative and obligate) to soluble smaller compounds, such as sugars, fatty acids, amino acids, peptides and a small amount of acetic acid, hydrogen, and carbon dioxide. *Acidogenesis:* The newly hydrolyzed sugars, fatty acids, amino acids and peptides are converted into volatile fatty acids, such as propionic and butyric acids, through a fermentation process. This stage also produces small amounts of acetic acid, hydrogen, and carbon dioxide.

Acetogenesis: The volatile fatty acids produced in the previous stage are fully converted to more acetic acid, hydrogen, and carbon dioxide.

Methanogenesis: In this phase metabolic methane is produced from both the acetic acid and hydrogen. These compounds are catalyzed by bacteria, that are obligate hydrogen-utilizing anaerobes, through the following biochemical reaction:

$$4H_4 + CO_2 \rightarrow CH_4 + 2H_2O \qquad \text{Equation 1.}$$

Conversion of hydrogen to methane reaction.

2.2.2. Kinetics

Several different models can be used for estimating kinetic parameters. However, the first-order kinetics model is widely applied and considered the oldest modeling in substrate utilization (Alvarez wt al., 2010; Cooney & Wise, 1975; Cuetos et al., 2011; Mac & Llabr, 2000; Nwabanne et al., 2009; Santos et al., 1999; Tomei et al., 2009; Weiland, 2010).

The basic equation is as follows:

$$\frac{dS}{dt} = -kS \qquad \text{Equation 2.}$$

Where k is known as the first order kinetic constant (time^{-1}) and S is the biodegradable substrate concentration (mass of VS).

As S is hard to measure, the accumulated methane production per unit of substrate added is used instead. The following equation is used for that purpose:

$$\frac{B_o - B}{B_o} = \frac{S}{S_o} \qquad \text{Equation 3.}$$

Where B is the methane yield after the digestion period (volume of CH_4/mass of substrate), B_o is the ultimate methane yield (volume of CH_4/mass of VS) and S_o is the initial biodegradable substrate concentration (mass of VS). From equations 2 and 3, the following equation can be derived:

$$\frac{B_o - B}{B_o} = e^{-kt} \qquad \text{Equation 4.}$$

Lastly, by solving for B (methane yield) the following equation is obtained:

$$B = B_o\,(1 - e^{-kt}) \qquad \text{Equation 5.}$$

This model considers microbial growth and the nutrient availability as limiting factors (Rodriguez Andara & Lomas Esteban, 1999). For this reason, the model describes the process once the methane production has reached its maximum, neglecting any considerations during the lag phase. Graphical linearization is typically used to determine the k value. Linearization was applied by Nwabanne et al. (2009) to determine kinetic parameters of anaerobic digestion of municipal waste. Also, regression coefficients can be applied to the first-order kinetic constants for adjustment (Alvarez et al., 2010).

2.2.3. Anaerobic Reactors

2.2.3.1. Batch-fed Digesters

A reactor in which there is no flow of mass across the system boundary during the digestion process can be defined as a batch reactor; batch-fed reactors operate as batch reactors fed periodically. Batch-fed reactors are typically filled and once the fixed retention time is completed reactors are emptied, to then introduce a new batch. Benefits with this type of reactor include their relative low cost for construction and operation when compared to continuous stirred tank reactors (CSTR), and greatly suited for seasonally produced biomass feeds (Chynoweth & Isaaccson, 1987). It is for this latter reason that the CSTR is preferred for waste manure, as it is not seasonally produced.

2.2.3.2. Continuous Stirred Tank Reactor (CSTR)

In contrast to batch-fed reactors, the flow of mass is constantly going into and out of continuous reactors, allowing for continuous production of biogas. Continuous reactors are widely used and typically used for sewage sludge digestion (Chynoweth & Isaaccson, 1987; Suryawanshi, Chaudhari, & Kothari, 2010). Reported advantages of CSTR include ability to process feeds with high levels of suspended solids, enhanced contact of microbiological species with the substrate, uniform substrate distribution in the tank, scum layer prevention if properly mixed, uniform substrate temperature distribution in the tank and easily modeled. Some limitations include large power requirements, complete mixing difficulty in large scale, incompletely digested effluent leaving system, loss of microorganisms with effluent (Chynoweth & Isaaccson, 1987). In a comparative research experiment conducted by Moset et al. (2014) it was determined that gradual manure addition in thermophilic continuously stirred anaerobic digesters produced greater methane yields when compared to abrupt manure additions after a period of substrate starvation (Moset et al., 2014).

2.2.4. Nature of inputs

2.2.4.1. Substrate composition

The composition of the substrate is also important to consider. Substrates higher in lipid and protein content have been proven to generate higher biogas rates when compared to substrates high in carbohydrates (Ferrer et al., 2014). In addition to lipid, protein, and carbohydrate content, the fiber content is also an important factor (Lesteur et al., 2010). Influent's concentration of volatile solids (VS) has also been determined of critical importance for the anaerobic digestion process. Several authors have reported low VS values are directly related to lower methane production rates (Y. Chen, Cheng, & Creamer, 2008; Hashimoto, 1983, 1984; McCarty, 1964; Yenigün & Demirel, 2013).

2.2.4.2. Animal Manure as Feedstock

Animal manure is a common feedstock in anaerobic digestion due to its high availability and its potential to provide useful products such as soil amendment and fuel (Khalid et al., 2011). Additionally, the animal manure's buffering capacity, which stabilizes the process, and nitrogen supply for microbial synthesis makes this feedstock one of the most used and studied for anaerobic digestion (Panichnumsin et al., 2010). The biogas production and methane yield of anaerobically digested manure is highly dependent on various factors such as livestock type, animal's growth stage, feeding quality and quantity, and animal's health status. The most studied animal waste in anaerobic digestion research is probably cow manure (Gontupil, 2013). Swine manure has been studied to a lesser degree, and most of those studies included co-digestion of swine manure and other carbon-rich products (Álvarez et al. , 2010; Cuetos et al., 2011; Fischer et al., 1983; Fujita et al., 1980). Table 1 shows many previous studies on anaerobic digestion of different sources of animal manure with different and without various co-substrates.

Table 1. Studies on methane yield in terms of kilograms of VS added using animal manure as substrate.

Substrate	Co-substrate	Methane yield (L/kg VS)	References
Cattle manure	Olive mill waste	179	Goberna et al. (2010)
Cattle manure	Agricultural waste and energy crops	620	Cavinato et al. (2010)
Cattle manure	Sugar beet tops	229	Lehtomäki et al. (2007)
Swine manure	Fish and bio-diesel waste	620	Alvarez et al. (2010)

Table 1 Continued

Swine manure	Corn stover	305	Fujita et al. (1980)
Swine manure	Wheat straw	220	Fischer et al. (1983)
Swine manure	Energy crops	357	Cuetos et al. (2011)
Chicken manure	Corn stover	328	Li et al. (2013)
Dairy manure	None	243	Labatut et al. (2011)
Swine Manure	None	300	Hansen et al. (1999)
Dewatered Swine Manure	None	538	Campos et al. (2008)
Sow manure	None	275	Moller et al. (2004)
Swine manure	None	356	Moller et al. (2004)
Chicken manure	None	270	Huang & Shih (1981)

Swine manure has been studied under various scales, temperatures, co-substrate combinations, and reactor type of in order to determine the practicality and viability of producing biogas. Swine manure co-digestion has been scarcely researched in comparison to co-digestion of dairy and cattle manure. Cuetos et al. (2011) researched anaerobic co-digestion of swine manure with various energy crops (sunflower, maize and rapeseed waste) in 3 different proportions (25,50, and 75% volatile solids) to determine the optimal feedstock combination to maximize biogas. He concluded that co-digestion increased biogas production, and that rapeseed waste yielded the highest amount of biogas compared with the other crops. Similarly, Fujita et al. (1980) concluded that co-digestion of swine manure and corn stover resulted in increased gas production by up to 65% under both mesophilic (39°C) and thermophilic conditions (55°C) in comparison with swine manure only. However, not all studies have shown increased biogas production under anaerobic co-digestion. Fischer et al. (1983) tested the methane production from co-digestion of swine manure and wheat straw under mesophilic conditions (35°C) and observed the highest gas production under manure alone as a substrate. In some cases research conducted on anaerobic digestion of swine manure without any co-substrates has shown comparable biogas and methane yields as anaerobic digestion with co-substrates (Campos et al., 2008; K. Hansen et al., 1999; Moller et al., 2004).

2.2.4.3. Moisture

Solid-state anaerobic digestion is typically considered for substrates with 15% or higher solids concentration (Rapport et al., 2008). On the other hand, liquid anaerobic digestion typically handles substrates with solid concentrations between 0.5-15% (Li et al., 2011). Numerous advantages have been found with high solids anaerobic digestion, such as smaller reactor volume, lower total energy loss, minimal material handling and comparable methane yields to liquid anaerobic digestion (Guendouz et al., 2008). It has been shown that the solid load in the substrate introduced in a digester affects microorganisms metabolic activity (Chen et al., 2008; Raposo et al., 2012). Drawbacks have also been described with high solids anaerobic digestion. In some cases retention time has been reported to be up to three times higher than liquid anaerobic digestion due to slower mass transport (Rapport et al., 2008). However, others have reported comparative similar hydraulic retention times between wet and dry anaerobic digestion. In a study published by Luning et al. (2003) the loading rate for a high-solids facility treating municipal solid waste was 7.7 kg VS/m^3, similar to a liquid facility digesting municipal solid waste at a rate of 6.8 kg VS/m^3.

2.2.5. Operational Parameters

2.2.5.1. Tank Operating Temperature

The temperature at which the digester operates is highly critical as it can significantly affect the conversion, kinetics, stability, effluent quality, and net energy of the biological conversion process. For practical process applications studies have categorized temperature ranges (Chynoweth & Isaaccson, 1987). The three main anaerobic digester operational ranges are: (a) Psychrophilic: < 20°C (b) Mesophilic: Between 20-45°C and (c) Thermophilic: Between 45-65°C (Raposo et al., 2012; U.S. Environmental Protection Agency, n.d.; Yenigün et al., 2013). It has been determined that as temperature increases, conversion rates are promoted but overall process stability decreases (Chynoweth & Isaaccson, 1987). In general, temperatures between 35-37°C are considered effective for methane production (Khalid et al., 2011). Advantages of thermophilic processes over mesophilic ones include not only higher rates of digestion, but also greater conversion of waste into biogas, faster solid-liquid separation, and bacterial and viral pathogens reduction (Cooney et al., 1975). For solid-state anaerobic digestion thermophilic temperatures are preferred, as they can shorten the start-up period and increase methane production, without significant increase of energy consumption (Li et al., 2011). Both mesophilic and thermophilic reactors have proven to be successful choices (De Baere, 2001). However, increased stability and significantly reduced energy expense make mesophilic operations more common (Khalid et al., 2011).

2.2.5.2. Tank pH Level

The pH is considered a crucial parameter in the anaerobic digestion process, as it significantly affects growth of the microorganisms (Y. Chen et al., 2008; Yadvika, Santosh, Sreekrishnan, Kohli, & Rana, 2004). It has also been shown to affect the equilibrium position between ammonia and ammonium under total ammonia nitrogen concentration (Hashimoto, 1983, 1984). Several publications suggest that a pH between 6.8-7.2 is desired for optimal digestion (Y. Chen et al., 2008; Hashimoto, 1983, 1984; Khalid et al., 2011; Raposo et al., 2012; Yadvika et al., 2004). Control of pH has proven to be important during the digestion process. If the pH is found to be outside the optimal range, with little buffering capacity, the process can be inhibited (Raposo et al., 2012). Higher pH levels result in higher ratios of free ammonia to ionized ammonia (NH_4^+). Ammonia in its free form has been suggested to be a toxic agent; an increase in pH would result in added toxicity (Chen et al., 2008). Low pH levels can be the result of little buffering capacity, and is also considered toxic as both methanogenic and acidogenic microorganisms have an optimal pH close to 7. Failing to maintain the appropriate pH range may result in digester failure due to acidification. How free ammonia, volatile fatty acids and pH interact is key, as while digestion may run stably, it may result in a lower methane production (Chen et al., 2008). According to Chen et al. (2008) this is known as “inhibited steady state”.

2.2.5.3. Hydraulic Retention Time

The Hydraulic Retention Time (HRT) is known as the average time the substrate takes in the reactor for digestion before it leaves the system. Digesters treating substrates with high solid concentrations tend to have longer retention times when compared to simple organic materials (Safferman et al., 2012). As the HRT becomes shorter, risks for washout of active bacterial population increase. On the other hand, as retention time increases the larger the total volume required for the digester, hence more capital cost can be expected (Yadvika et al., 2004). Retention time and operating temperature have been determined to be highly related, as maximum biogas production will often be dependent on how those two parameters interact (Kim et al., 2006).

2.2.5.4. Substrate/Inoculum Ratio

In order to degrade the primary and intermediary products during the anaerobic digestion cycle it is key to ensure sufficient bacteria is present in the reactor, to achieve maximum methane production. Substrate/inoculum ratio has been reported to affect methane production in anaerobic digestion of various different substrates (Chen & Hashimoto, 1996; Gonzalez-Fernandez & Garcıa-Encina, 2009; Gunaseelan, 1994; Hashimoto, 1989). For instance, in a study done with ball-milled straw as main substrate by Hashimoto (1989) it was found that inoculum size and fermentation time significantly affect the methane yield. Comparably, in a study conducted by Gonzalez-Fernandez and Garcıa-Encina (2009), where swine slurry was used in batch tests as main substrate, it was found that methane rates were different as the substrate/inoculum ratio changed. The study confirms variability occurs due to the presence of volatile fatty acids (Gonzalez-Fernandez & Garcıa-Encina, 2009).

2.2.6. Benefits of Outputs

The end products of the anaerobic digestion prove to be beneficial in many different ways. Biogas production and utilization provides a large opportunity for creating revenue for farmers (Safferman et al., 2012). Other by-products include nutrient recovery from the digestion effluent with desirable characteristics (reduced pathogens and odor) and a stable solid product with a better N/P ratio than raw manure for crop production) (McCarty, 1964).

2.2.6.1. Renewable Energy Source

Anaerobic digestion has shown to be a promising source of energy that supports the energy production. For example, countries such as Germany and Denmark are leaders in the use of anaerobic digestion technology, and have up to 9% and 15%, respectfully, of their consumed electricity being provided by biomass and waste renewable sources, respectively. (Cuetos et al., 2011; EIA, 2012; Weiland, 2010). The total electricity consumption in 2011 in the United States was recorded to be 3,882 Billion Kilowatt-hour. From that total only about 1.8% represented the total energy consumption provided by biomass and waste renewable sources. Animal waste can be highly valuable as a renewable energy resource if treated correctly (Holm-Nielsen et al., 2009). Biogas has been determined to be a respectable source of renewable energy for electricity production, capable of substituting fossil fuel energies such as coal, oil and natural gas. Anaerobic digestion systems can potentially significantly reduce uncontrolled fugitive methane emissions from stored manure if properly designed. According to Kaparaju & Rintala (2011), anaerobic digestion is the only technology capable of yielding positive energy balances while reducing GHG emissions. Additionally, biogas comes with certain advantages as it can be produced as required and can be easily stored. Biogas also has equivalent applications to natural gas, so it can be simply distributed through existent natural gas infrastructure as long as moisture and hydrogen sulfide have been reduced by significant amounts (Kaparaju et al., 2011; Massé et al., 2011). Anaerobic digestion can contribute to sustainability goals by reducing GHG emissions.

2.2.6.2. Agronomic Use

Digested manure is known to have great value as it conserves original crop nutrients (Safferman et al., 2012). During the digestion process mineralization of organically bound nutrients is known to occur and the effluent has a lower C/N ratio (Field et al., 1984; Massé et al., 2007). Lower C/N ratio has been related to an increase in the short-term N fertilization effect. Such effect allows more accurate nitrogen dosage and reduced mineral nitrogen applications in a fertilization plan (Tafdrup, 1995). When digested manure was compared to raw waste it was found to have an improved phosphorous fertilizing effect (Messner et al., 1987). Likewise, the N/P ratio in the digestate has also been found to be higher. Massé et al. (2011) found this high N/P ratio matched the crop nutrients requirements more closely. Under the right conditions, anaerobically digested manure has also been determined to reduce weed seed viability thereby reducing needs of herbicide applications (Massé et al., 2011). This may be of great interest to organic farmers, as a non-synthetic nutrient source for crop production. Another significant benefit attributed to digester effluent is the potential it can have for acid soils remediation. The pH of the effluent has been repeatedly determined to be considerably more basic when compared to raw manure (Field et al., 1984; D.I. Massé et al., 2011; Messner et al., 1987)

2.2.6.3. Odor and Pathogen Reduction

Food animal production has evolved to highly concentrated operations separated from crop production. Therefore, the amount of manure produced often exceeds the local need of fertilizer (Vanotti et al., 2009). One of many benefits of anaerobically digested manure is the reduced odor and pathogen levels of the effluent and waste solids (Alfa et al., 2014; Li et al., 2011; Protection & Agstar, 2011; Sahlstr, 2003). In some cases, these benefits result in easier transportation. For instance, digested slurry is commonly post-treated to produce fertilizer in pellets and distributed internationally as commercial fertilizer (Tafdrup, 1995). High-solid anaerobic digestion effluent has also been known to be used for energy when pressed into fuel pellets (Safferman et al., 2012).

Anaerobic digestion under the right treatment is capable of inactivating weed seeds, bacteria, viruses, and parasites originally found in manure. This is key if used as fertilizer (Weiland, 2010). Many factors such as temperature, treatment time, pH, volatile fatty acids, batch or continuous system, bacterial species and available nutrients play an important role in regards to pathogen reduction. The most critical factor is considered to be temperature (Sahlstr, 2003). *Salmonella*, one of the most common and most likely to be spread through land application, has proven to be significantly reduced under both mesophilic (30-38°C) and thermophilic conditions (50-55°C). Up to 90% Salmonella reduction can be achieved through thermophilic temperatures. Thermophilic conditions are more efficient in pathogen reduction when compared to mesophilic ones (Bagge et al., 2005; Weiland, 2010).

In the case of "ready-to-eat" crops, for both local and international consumption, pathogen reduction is key as it reduces human consumption risks (Vanotti et al., 2009). Lastly, the digested effluent has been recorded to have significantly reduced odors at time of spreading, as well as reduced sources of flies and rodents in application site (Holm-Nielsen et al., 2009).

3. Conclusion

In order to achieve sustainable development in the agricultural and biological field considerations for the social, political, and economic factors need to be considered as much as technological ones. Hunger and food security are intimately related to the global context as much as to the local means of food production. Food security and anaerobic digestion technology are two aspects, one socially oriented, while the other being more technologically oriented, that give opportunity for creative thinking, at both global and local levels, to introduce sustainable development.

The production of biogas through anaerobic digestion systems of various types of industrial, agricultural and residential waste is both common and effective in many European countries, particularly Germany and Denmark (Weiland, 2010). Despite its multiple benefits, anaerobic digestion in the United States has not been widely implemented. This is largely due to low energy prices, lack of technical and applied research and understanding, early failures, unpredictable market conditions, inconsistencies across federal, state and local governments and lack of incentives and financial support (Switzenbaum, 1995; USDA, 2014).

Anaerobic digestion, as a sustainable solution to the waste management challenge of hog farms in North Carolina, is of great interest as it addresses main environmental and health concerns. Additionally, when paired with other technologies, it has the potential to produce marketable products. However, limited research has been conducted on anaerobic digestion of swine manure, and no research has ever been conducted on anaerobic digestion of scraped swine manure with a higher solids content. Research performed on anaerobic digestion of swine manure typically tests manure that has been collected from the barn flushed waste, which is typically greatly diluted. The introduction of the scraper system technology in North Carolina hog farms allows the collection of swine manure scraped solids and scraped whole slurry.

References

Alfa, M. I., Adie, D. B., Igboro, S. B., Oranusi, U. S., Dahunsi, S. O., & Akali, D. M. (2014). Assessment of biofertilizer quality and health implications of anaerobic digestion effluent of cow dung and chicken droppings. *Renewable Energy*, *63*, 681–686. http://doi.org/10.1016/j.renene.2013.09.049

Álvarez, J. A., Otero, L., & Lema, J. M. (2010). A methodology for optimising feed composition for anaerobic co-digestion of agro-industrial wastes. *Bioresource Technology*, *101*(4), 1153–1158. http://doi.org/10.1016/j.biortech.2009.09.061

Alvarez, J. a, Otero, L., Lema, J. M., & Omil, F. (2010). The effect and fate of antibiotics during the anaerobic digestion of pig manure. *Bioresource Technology*, *101*(22), 8581–6. http://doi.org/10.1016/j.biortech.2010.06.075

American Public Health Association. (2012). *Standard methods for the examination of water and wastewater.* (E. W. Rice, R. B. Baird, A. D. Eaton, & L. S. Clesceri, Eds.) (22nd ed.). Washington DC: American Public Health Association.

Amin, S. (1976). Unequal Development: An Essay on the Formation of Peripheral Capitalism. *Monthly Review Press.*

Appelbaum, R. P., & Robinson, W. I. (2005). *Critical globalization studies*. New York: Routledge.

Bagge, E., Sahlström, L., & Albihn, A. (2005). The effect of hygienic treatment on the microbial flora of biowaste at biogas plants. *Water Research*, *39*(20), 4879–86. http://doi.org/10.1016/j.watres.2005.03.016

Barker, J. C. (1996). *Lagoon Design and Management For Livestock Waste Treatment and Storage*. *NC State University Cooperative Extension* (Vol. 103). Retrieved from https://www.bae.ncsu.edu/extension/ext-publications/waste/animal/ebae-103-83-lagoon-design-barker.pdf

Battye, R., Battye, C., Overcash, C., & Fudge, S. (1994). *Development and Selection of Ammonia Emission Factors*. Research Triangle park. Durham, NC.

Boe, K., Kougias, P. G., Pacheco, F., O-Thong, S., & Angelidaki, I. (2012). Effect of substrates and intermediate compounds on foaming in manure digestion systems. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *66*(10), 2146–54. http://doi.org/10.2166/wst.2012.438

Boske, J., Wirth, B., Garlipp, F., Mumme, J., & Van den Weghe, H. (2015). Upflow anaerobic solid-state (UASS) digestion of horse manure: Thermophilic vs. mesophilic performance.

Bioresource Technology, *175*, 8–16. http://doi.org/10.1016/j.biortech.2014.10.041

Brady, D., Kaya, Y., & Beckfield, J. (2007). Reassessing the effect of economic growth on well-being in less-developed countries, 1980-2003. *Studies in Comparative International Development*, *42*(1–2), 1–35. http://doi.org/10.1007/s12116-007-9003-7

Campos, E., Almirall, M., Mtnez-Almela, J., Palatsi, J., & Flotats, X. (2008). Feasibility study of the anaerobic digestion of dewatered pig slurry by means of polyacrylamide. *Bioresource Technology*, *99*(2), 387–95.http://doi.org/10.1016/j.biortech.2006.12.008

Carolan, M. (2012). *The Sociology of Food and Agriculture*. London, New York: Routledge.

Cavinato, C., Fatone, F., Bolzonella, D., & Pavan, P. (2010). Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy crops: Comparison of pilot and full scale experiences. *Bioresource Technology*, *101*(2), 545–550. http://doi.org/10.1016/j.biortech.2009.08.043

Chase-Dunn, C. (1989). *Global Formation: Structures of the Global Economy. American Sociological Review*. Cambridge, MA: Basil Blackwell.

Chase-Dunn, C. (2006). "Globalization: A World-Systems Perspective." In C. Chase-Dunn & S. Babones (Eds.), *Global Social Change: Historical and Comparative Perspectives*. Baltimore: The Johns Hopkins University Press.

Chen, T. H., & Hashimoto, A. G. (1996). Effects of pH and substrate: Inoculum ratio on Batch Methane Fermentation. *Bioresource Technology*, *56*, 179–186.

Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource Technology*, *99*(10), 4044–64. http://doi.org/10.1016/j.biortech.2007.01.057

Cheng, J. (Ed.). (2010). *Biomass to Renewable Energy Processes*. CRC Press, Taylor & Francis Group.

Chynoweth, D. P., & Isaaccson, R. (1987). *Anaerobic Digestion of Biomass* (1st ed.). Elsevier Applied Science.

Comte, A. (1824). A general view of positivism. New York: Appleton.

Conway, G. (1998). *The doubly green revolution: food for all in the twenty-first century*.

Ithaca: Comstock Pub. Associates.

Cooney, C. L., & Wise, D. L. (1975). Thermophilic Anaerobic Digestion of Solid Waste for Fuel Gas Production. *Biotechnology and Bioengineering*, *XVII*, 1119–1135.

Crouse, D. A., Barker, J. C., & Havlin, J. L. (n.d.). *Use of On-Farm Records for Modifying a Certified Animal Waste Management Plan*. Raleigh, NC. Retrieved from http://www.ncagr.gov/SWC/tech/documents/AppenxFarmRecordsAG-439-42.pdf

Cuetos, M. J., Fernández, C., Gómez, X., & Morán, A. (2011). Anaerobic co-digestion of swine manure with energy crop residues. *Biotechnology and Bioprocess Engineering*, *16*(5), 1044–1052. http://doi.org/10.1007/s12257-011-0117-4

De Baere, L. (2001). Anaerobic digestion of solid waste : state-of-the-art. *Waster Science and Technology*, 283–290.

De Janvry, A. (1981). *The agrarian question and reformism in Latin America*. Baltimore: The Johns Hopkins University Press.

De Vries, J. W., Vinken, T. M. W. J., Hamelin, L., & De Boer, I. J. M. (2012). Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy--a life cycle perspective. *Bioresource Technology*, *125*, 239–48. http://doi.org/10.1016/j.biortech.2012.08.124

Dincer, I. (2010). *Global Warming*. (I. Dincer, A. Hepbasli, A. Midilli, & T. H. Karakoc, Eds.). Boston, MA: Springer US. http://doi.org/10.1007/978-1-4419-1017-2

Drosg, B., Braun, R., Bochmann, G., & Al Saedi, T. (2013). *Analysis and characterisation of biogas feedstocks*. *Woodhead Publishing Series in Energy*. http://doi.org/http://dx.doi.org/10.1533/9780857097415.1.52

Durkheim, E. (1984). *The division of labor in society*. New York: Free Press.

El-Mashad, H. M., & Zhang, R. (2010). Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology*, *101*(11), 4021–4028. http://doi.org/10.1016/j.biortech.2010.01.027

Energy Information Administration. (2013). *EIA projects world energy consumption will increase 56% by 2040*. United States. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=12251

Environmental Protection Agency. (2014). *Global Greenhouse Gas Emissions*. Retrieved from http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

Esposito, G., Frunzo, L., Liotta, F., Panico, A., & Pirozzi, F. (2012). Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates. *The Open Environmental Engineering Journal*, *5*(1), 1–8. http://doi.org/10.2174/1874829501205010001

Fan, S., & Rosegrant, M. (2008). Investing in agriculture to overcome the world food crisis and reduce poverty and hunger. *IFPRI Policy Brief*, *3*(June), 4. Retrieved from http://sanrem.cals.vt.edu/1323/investing in agriculture.pdf

Ferrer, P., Cambra-López, M., Cerisuelo, A., Peñaranda, D. S., & Moset, V. (2014). The use of agricultural substrates to improve methane yield in anaerobic co-digestion with pig slurry: effect of substrate type and inclusion level. *Waste Management (New York, N.Y.)*, *34*(1), 196–203. http://doi.org/10.1016/j.wasman.2013.10.010

Field, J. A., Caldwell, J. S., Jeyanayagam, S., Reneau, R. B., Kroontje, W., & Collins, E. R. (1984). Fertilizer Recovery from Anaerobic Digesters. *Transactions of the ASAE*, 56–60.

Firebaugh, G. (1996). Does Foreign Capital Harm Poor Nations? New Estimates Based on Dixon and Boswell's Measures of Capital Penetration. *American Journal of Sociology*, *102*(2), 563. http://doi.org/10.1086/230957

Fischer, J. R., Ianotti, E. L., & Fulhage, C. D. (1983). Production of methane gas from combinations of wheat straw and swine manure. *Transactions of the ASAE*, *26*(2), 546–548.

Food and Agricuture Organization. (1998). *The FAO Definition of Sustainable Development and the Code of Conduct for Responsible Fisheries: an analysis of the related principles, criteria and indicators*. Rome.

Food and Agricuture Organization. (2004). *The State of Food and Agriculture 2003–2004*. Rome.

Frank, A. G. (1966). The Development of Underdevelopment. *Monthly Review Press.*, *18*, 17–

31.

Fujita, M., Scharer, J. M., & Moo-Young, M. (1980). Effect of corn stover addition on the anaerobic digestion of swine manure. *Agricultural Wastes*, *2*(3), 177–184. http://doi.org/10.1016/0141-4607(80)90014-1

Galli, R. E. (1981). *The Political economy of rural development : peasants, international capital, and the state : case studies in Columbia, Mexico, Tanzania, and Bangladesh*. Albany: State University of New York Press.

Goberna, M., Schoen, M. A., Sperl, D., Wett, B., & Insam, H. (2010). Mesophilic and thermophilic co-fermentation of cattle excreta and olive mill wastes in pilot anaerobic digesters. *Biomass and Bioenergy*, *34*(3), 340–346. http://doi.org/10.1016/j.biombioe.2009.11.005

Gonçalves, M. R., Costa, J. C., Marques, I. P., & Alves, M. M. (2011). Inoculum acclimation to oleate promotes the conversion of olive mill wastewater to methane. *Energy*, *36*(4), 2138–2141. http://doi.org/10.1016/j.energy.2010.04.042

Gontupil, J. (2013). *Anaerobic Co-digestion of Swine Manure and Agricultural Residues for Biogas Production*. North Carolina State University.

Gonzalez-Fernandez, C., & Garcıa-Encina, P. A. (2009). Impact of substrate to inoculum ratio in anaerobic digestion of swine slurry. *Biomass and Bioenergy*, *33*, 1065–1069. http://doi.org/10.1016/j.biombioe.2009.03.008

Guendouz, J., Buffière, P., Cacho, J., Carrère, M., & Delgenes, J.-P. (2008). High-solids anaerobic digestion: comparison of three pilot scales. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *58*(9), 1757–63. http://doi.org/10.2166/wst.2008.521

Gunaseelan, V. N. (1994). Effect of Inoculum/Substrate ratio a pretreatments on methane yield from Parthenium. *Biomass and Bioenergy*, *8*(1), 39–44.

Hansen, K., Angelidaki, I., & Ahring, B. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8). Retrieved from http://www.sciencedirect.com/science/article/pii/S0043135498004102

Hansen, K. H., Angelidaki, I., & Ahring, B. K. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8), 1805–1810. http://doi.org/10.1016/S0043-1354(98)00410-2

Hashimoto, A. G. (1983). Thermophilic and Mesophilic Anaerobic Fermentation of Swine Manure. *Agricultural Wastes*, *6*, 175–191.

Hashimoto, A. G. (1984). Methane from Swine Manure : Effect of Temperature and Influent Substrate Concentration on Kinetic Parameter (K). *Agricultural Wastes*, *9*, 299–308.

Hashimoto, A. G. (1989). Effect of Inoculum [Substrate Ratio on Methane Yield and Production Rate from Straw Experiment design. *Biological Wastes*, *28*, 247–255.

Hindle, T. (2008). *The Economist Guide to Management Ideas and Gurus*. (The Economist, Ed.). Bloomberg Press.

Hoffmann, R. A., Garcia, M. L., Veskivar, M., Karim, K., Al-Dahhan, M. H., & Angenent, L. T. (2008). Effect of shear on performance and microbial ecology of continuously stirred anaerobic digesters treating animal manure. *Biotechnology and Bioengineering*, *100*(1), 38–48. http://doi.org/10.1002/bit.21730

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*, *100*(22), 5478–84. http://doi.org/10.1016/j.biortech.2008.12.046

Huang, J. J. H., & Shih, J. C. H. (1981). The potential of biological methane generation from chicken manure. *Biotechnology and Bioengineering*, *23*(10), 2307–2314. http://doi.org/10.1002/bit.260231013

Inkeles, A. (1975). Becoming Modern: Individual Change in Six Developing Countries. *American Anthropological Association Stable*, *3*(2), 323–342.

International Energy Statistics. (2012).

IPCC. (1997). *Guidelines for National Greenhouse Gas Inventories: Reference Manual*.

Jenkins, J. C., & Scanlan, S. J. (2001). Food Security in Less Developed Countries, 1970 To 1990. *American Sociological Review*, *66*(5), 718–744.http://doi.org/10.2307/3088955

Jenkins, J. C., Scanlan, S. J., & Peterson, L. (2007). Military Famine, Human Rights, and Child

Hunger: A Cross-National Analysis, 1990-2000. *The Journal of Conflict Resolution*, *51*(6), 823-827-833-847. Retrieved from http://search.proquest.com/docview/224558559?accountid=10673

Jeong, E., Kim, H. W., Nam, J. Y., & Shin, H. S. (2010). Enhancement of bioenergy production and effluent quality by integrating optimized acidification with submerged anaerobic membrane bioreactor. *Bioresource Technology*, *101*(1 SUPPL.), S7–S12. http://doi.org/10.1016/j.biortech.2009.04.064

Kaparaju, P., & Rintala, J. (2011). Mitigation of greenhouse gas emissions by adopting anaerobic digestion technology on dairy, sow and pig farms in Finland. *Renewable Energy*, *36*(1), 31–41. http://doi.org/10.1016/j.renene.2010.05.016

Khalid, A., Arshad, M., Anjum, M., Mahmood, T., & Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste Management (New York, N.Y.)*, *31*(8), 1737–44. http://doi.org/10.1016/j.wasman.2011.03.021

Kick, E. L., McKinney, L. a., & Thompson, G. H. (2011). Intensity of food deprivation: The integrative impacts of the world system, modernization, conflict, militarization and the environment. *International Journal of Comparative Sociology*, *52*(6), 478–502. http://doi.org/10.1177/0020715211428181

Kim, J. K., Oh, B. R., Chun, Y. N., & Kim, S. W. (2006). Effects of temperature and hydraulic retention time on anaerobic digestion of food waste. *Journal of Bioscience and Bioengineering*, *102*(4), 328–32. http://doi.org/10.1263/jbb.102.328

Krugman, P. (1999). *The return of depression economics*. New York: W. W. Norton.

Labatut, R. A., Angenent, L. T., & Scott, N. R. (2011). Biochemical methane potential and biodegradability of complex organic substrates. *Bioresource Technology*, *102*(3), 2255–2264. http://doi.org/10.1016/j.biortech.2010.10.035

Lehtomaki, A., Huttunen, S., & Rintala, J. A. (2007). Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio. *Resources, Conservation and Recycling*, *51*(3), 591–609. http://doi.org/10.1016/j.resconrec.2006.11.004

Lesteur, M., Bellon-Maurel, V., Gonzalez, C., Latrille, E., Roger, J. M., Junqua, G., & Steyer, J. P. (2010). Alternative methods for determining anaerobic biodegradability: A review. *Process Biochemistry*, *45*(4), 431–440. http://doi.org/10.1016/j.procbio.2009.11.018

Li, Y., Park, S. Y., & Zhu, J. (2011). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews*, *15*(1), 821–826. http://doi.org/10.1016/j.rser.2010.07.042

Li, Y., Zhang, R., Liu, X., Chen, C., Xiao, X., Feng, L., … Liu, G. (2013). Evaluating Methane Production from Anaerobic Mono- and Co-digestion of Kitchen Waste, Corn Stover, and Chicken Manure. *Energy & Fuels*, *27*(4), 2085–2091. http://doi.org/10.1021/ef400117f

Liang, Z. S., Westerman, P. W., & Arogo, J. (2002). Modeling Ammonia Emission from Swine Anaerobic Lagoons, *45*(3), 787–798.

Lipton, M. (1975). Urban bias and food policy in poor countries. *Food Policy*, *1*(1), 41–52. http://doi.org/10.1016/0306-9192(75)90007-X

Lipton, M. (1977). *Why poor people stay poor : urban bias in world development*. Cambridge: Harvard University Press.

Luning, L., van Zundert, E. H. M., & Brinkmann, A. J. F. (2003). Comparison of dry and wet digestion for solid waste. *Water Science and Technology*, *48*(4), 15–20.

Machethe, C. (2004). Agriculture and poverty in South Africa: Can agriculture reduce poverty. In *Overcoming Underdevelopment Conference* (pp. 1–14). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.1551&rep=rep1&type=pdf

Mallin, M. (2000). Impacts of Industrial Animal Production on Rivers and Estuaries. *American Scientist*, *88*(1), 26. http://doi.org/10.1511/2000.1.26

Massé, D. I., Croteau, F., & Masse, L. (2007, November). The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors. *Bioresource Technology*. http://doi.org/10.1016/j.biortech.2006.07.040

Massé, D. I., Talbot, G., & Gilbert, Y. (2011). On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations. *Animal Feed Science* *and Technology*, *166–167*, 436–445. http://doi.org/10.1016/j.anifeedsci.2011.04.075

Mata-Alvarez, J., & Llabres, S. M. (2000). Anaerobic digestion of organic solid wastes . An overview of research achievements and perspectives. *Bioresource Technology*, *74*, 3–16.

McCarty, P. L. (1964). Anaerobic Waste Treatment Fundamentals I: Chemistry and Microbiology. *Public Works*, 107–112.

McMichael, P. (2009). A food regime genealogy. *Journal of Peasant Studies*, *36*(1), 139–169. http://doi.org/10.1080/03066150902820354

Mebratu, D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, *18*(6), 493–520. http://doi.org/10.1016/S0195-9255(98)00019-5

Messner, H., & Amberger, A. (1987). Composition, nitrification and fertilizing effect of anaerobically fermented slurry. *Agricultural Waste Management and Environmental Protection*, 125–130.

Moller, H. B., Sommer, S. G., & Ahring, B. K. (2004). Methane productivity of manure, straw and solid fractions of manure. *Biomass and Bioenergy*, *26*(5), 485–495. http://doi.org/10.1016/j.biombioe.2003.08.008

Moody, L. B., Burns, R. T., Bishop, G., Sell, S. T., & Spajic, R. (2011). Using Biochemical Methane Potential Assays to Aid in Co-substrate Selection for Co- digestion. *Transactions of the ASABE*, *27*(3), 433–439.

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, *1*(1), 1–27. http://doi.org/10.14448/jes.01.0002

Moritzer, E. (2008). Curse or blessing? *Kunststoffe International*, *98*(3), 38–39.

Moset, V., Bertolini, E., Cerisuelo, A., Cambra, M., Olmos, A., & Cambra-López, M. (2014). Start-up strategies for thermophilic anaerobic digestion of pig manure. *Energy*, *74*, 389–395. http://doi.org/10.1016/j.energy.2014.07.003

Ni, J.-Q., Heber, A. J., Sutton, A. L., Kelly, D. T., Patterson, J. a, & Kim, S.-T. (2010). Effect of swine manure dilution on ammonia, hydrogen sulfide, carbon dioxide, and sulfur dioxide releases. *The Science of the Total Environment*, *408*(23), 5917–23.

http://doi.org/10.1016/j.scitotenv.2010.08.031

Nizami, A.-S., & Maclean, H. L. (2013). Anaerobic Digesters : challenges and perspectives. In N. Korres, P. O'Kiely, J. Benzie, & J. West (Eds.), *Bioenergy Production by Anaerobic Digestion Using Agricultural Biomass and Organic Waste*. Routledge, Taylor and Francis. http://doi.org/10.13140/2.1.1405.0241

Nwabanne, J. T., Onukwuli, O. D., & Ifeakandu, C. M. (2009). Biokinetics of Anaerobic Digestion of Municipal Waste. *International Journal Environmental Resources*, *3*(4), 511–517.

Panichnumsin, P., Nopharatana, A., Ahring, B., & Pawinee, C. (2010). Production of methane by co-digestion of cassava pulp with various concentrations of pig manure. *Biomass and Bioenergy*, *34*(8), 1117–1124.

Parsons, T. (1964). *Social structure and personality.* New York: Free Press of Glencoe.

Penn State Extension. (n.d.). *Agronomy Guide* (AGRS-026). State College, PA. Retrieved from http://extension.psu.edu/agronomy-guide/cm/sec2/sec28

Penn State Extension. (2016). *Anaerobic Digestion: Biogas Production and Odor Reduction from Manure*. State College, PA. Retrieved from http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/projects/g-77

Pham, C. H., Triolo, J. M., Cu, T. T. T., Pedersen, L., & Sommer, S. G. (2013). Validation and recommendation of methods to measure biogas production potential of animal manure. *Asian-Australasian Journal of Animal Sciences*, *26*(6). http://doi.org/10.5713/ajas.2012.12623

Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308.

Protection, U. S. E., & Agstar, A. (2011). Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures, (March).

Raposo, F., Banks, C. J., Siegert, I., Heaven, S., & Borja, R. (2006). Influence of inoculum to substrate ratio on the biochemical methane potential of maize in batch tests, *41*, 1444–1450. http://doi.org/10.1016/j.procbio.2006.01.012

Raposo, F., De la Rubia, M. a., Fernández-Cegrí, V., & Borja, R. (2012). Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews*, *16*(1), 861–877. http://doi.org/10.1016/j.rser.2011.09.008

Raposo, F., Fernandez-Cegri, V., de la Rubia, M. A., Borja, R., Beline, F., Cavinato, C., … de Wilde, V. (2011). Biochemical methane potential (BMP) of solid organic substrates: Evaluation of anaerobic biodegradability using data from an international interlaboratory study. *Journal of Chemical Technology and Biotechnology*, *86*(8), 1088–1098. http://doi.org/10.1002/jctb.2622

Rapport, J., Zhang, R., Jenkins, B., & Williams, R. (2008). *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste*. *IWMB-2008-0011*. California. Retrieved from http://www.calrecycle.ca.gov/publications/Detail.aspx?PublicationID=1275

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384. http://doi.org/10.1016/j.ecolecon.2003.10.017

Rodriguez Andara, A., & Lomas Esteban, J. M. (1999). Kinetic study of the anaerobic digestion of the solid fraction of piggery slurries. *Biomass and Bioenergy*, *17*, 435–443.

Rostow, W. (1960). *The stages of economic growth: a non-communist manifesto*. New york: Cambridge University Press.

Safferman, S. I., Kirk, D. M., Faivor, L. L., & Wu-haan, W. (2012). Anaerobic Digestion Processes. In *Bioremediation and Sustainability* (pp. 103–136). http://doi.org/10.1002/9781118371220.ch3

Sahlstr, L. (2003). A review of survival of pathogenic bacteria in organic waste used in biogas plants, *87*, 161–166.

Santos, V. E., Naval, L., Guardiola, E., & Lo, B. (1999). Kinetic model for anaerobic digestion of livestock manure, *25*, 55–60.

SAS Institute Inc. (2013). Cary, NC.

Scanlan, S. J. (2001). Guns, butter, and development: Security and military famine extensions of the modernization versus dependency debate. *Journal of Political & Military Sociology*, *29*(2), 331–355.

Schiffman, S. S., Studwell, C. E., Landerman, L. R., Berman, K., & Sundy, J. S. (2005). Symptomatic Effects of Exposure to Diluted Air Sampled from a Swine Confinement Atmosphere on Healthy Human Subjects. *Environmental Health Perspectives*, *113*(5), 567–76. http://doi.org/10.1289/ehp.6814

Schinasi, L., Horton, R. A., Guidry, V., Wing, S., Marshall, S., & Morland, K. (2011). Air Pollution, Lung Functions, and Physical Symptoms in Communities near concentrated Swine Feeding Operations.pdf. *Epidemiology*, *22*(2), 208–15.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford: Clarendon Press.

Skorov, G. (1973). The green revolution and social progress. *World Development*, *1*(11), 13–21.

Stromberg, S., Nistor, M., & Liu, J. (2014). Towards eliminating systematic errors caused by the experimental conditions in Biochemical Methane Potential (BMP) tests. *Waste Management*, *34*(11), 1939–1948. http://doi.org/10.1016/j.wasman.2014.07.018

Sunkel, O. (1969). National development policy and external dependence in Latin America. *Journal of Development Studies*. http://doi.org/10.1080/00220386908421311

Suryawanshi, P. C., Chaudhari, A. B., & Kothari, R. M. (2010). Mesophilic anaerobic digestion : first option for waste treatment in tropical regions, *30*(March), 259–282. http://doi.org/10.3109/07388551.2010.487047

Switzenbaum, M. S. (1995). Obtacles in the Implementation of Anaerobic Treatment Technology. *Bioresource Technology*, *53*(95), 255–262.

Tafdrup, S. (1995). Viable Energy Production And Waste Recycling From Anaerobic Digestion Of Manure And Other Biomass Materials. *Biomass and Bioenergy*, *9*(95), 303–314.

Thompson, G. H. (2012). *A Macro-Comparative Analysis of Global Hunger across*

Developing Countries: The Integrative Impacts of Global and National Development, Gendered Inequalities, Conflict and Militarization, the Global Food System, and Environment. PhD Proposal. North Carolina State University. http://doi.org/10.1017/CBO9781107415324.004

Toman, M. a. (1992). The difficulty in defining sustainability. *Rources*. http://doi.org/10.4324/9781936331642

Tomei, M. C., Braguglia, C. M., Cento, G., & Mininni, G. (2009). Modeling of Anaerobic Digestion of Sludge. *Critical Reviews in Environmental Science and Technology*, *39*(12), 1003–1051. http://doi.org/10.1080/10643380801977818

U.S. Environmental Protection Agency. (n.d.). Overview of Anaerobic Digestion and Digesters. Retrieved from http://www.epa.gov/region2/webinars/pdfs/3-24-10_1.pdf

United States Department of Agriculture. (2007). *Hog and Pig Farming*.

United States Department of Agriculture. (2014). *Biogas Opportunities Roadmap*. Retrieved from http://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf

United States Department of Agriculture, N. R. C. S. (2012). Agricultural Wastes and Water, Air , and Animal Resources. In *Agricultural Waste Management Field Handbook* (p. Part 651). USDA.

United States Department of Agriculture, & Department of Commerce. (1982). Census of Agriculture. http://doi.org/10.5962/bhl.title.18473

United States Department of Agriculture, & National Agricultural Statistics Service. Census of Agriculture, Pub. L. No. AC-12-A-51 (2012). United States.

United States Environmental Protection Agency. (1983). *Methods for Chemical Analysis of Water and Wastes*. Cincinatti, OH.

US Department of Agriculture National Agricultural Service. (1988). Census of Agriculture. Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Department of Agriculture National Agricultural Service. (2014). Census of Agriculture.

US Department of Agriculture National Agricultural Service. (2015). Census of Agriculture.

Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Environmental Protection Agency. (1999). *Feedlots Point Source Category Study*. Retrieved from http://water.epa.gov/scitech/wastetech/guide/cafo/feedlots_index.cfm

Vanderholm, D., & Melvin, S. (2009). *Scraper Systems for Removing Manure From Swine Facilities*.

Vanotti, M., Szogi, A., Pilar Bernal, M., & Martinez, J. (2009). Livestock waste treatment systems of the future: a challenge to environmental quality, food safety, and sustainability. OECD Workshop. *Bioresource Technology*, *100*(22), 5371–3. http://doi.org/10.1016/j.biortech.2009.07.038

Vedrenne, F., Beline, F., Dabert, P., & Bernet, N. (2008). The effect of incubation conditions on the laboratory measurement of the methane producing capacity of livestock wastes. *Bioresource Technology*, *99*(1), 146–155. http://doi.org/10.1016/j.biortech.2006.11.043

Vos, R. O. (2007). Defining Sustainability: a conceptual orientation. *Journal of Chemical Technology & Biotechnology*, *82*(May), 334–339. http://doi.org/10.1002/jctb

Wallerstein, I. (1974). *The Modern World System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century.* New York, NY: Academic Press.

Weiland, P. (2010). Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology*, *85*(4), 849–60. http://doi.org/10.1007/s00253-009-2246-7

Williams, C. M. (2006). *Cost and Returns Analysis of Manure Management Systems Evaluated in 2004 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers*. Raleigh, NC.

Wing, S., & Wolf, S. (2000). Intensive livestock operations, health, and quality of life among eastern North Carolina residents. *Environmental Health Perspectives*, *108*(3), 233–238. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1637983/

World Bank. (2007). *World Development Report: Agriculture for Development.* Washington DC.

World Commision of Environment and Development. (1987). *Our Common Future*. *United Nations*. New York. http://doi.org/10.1080/07488008808408783

Yadvika, Santosh, Sreekrishnan, T. R., Kohli, S., & Rana, V. (2004). Enhancement of biogas production from solid substrates using different techniques--a review. *Bioresource Technology*, *95*(1), 1–10. http://doi.org/10.1016/j.biortech.2004.02.010

Yargeau, V. (2014). *Biomethane Potential (BMP) Assay Protocol*.

Yenigün, O., & Demirel, B. (2013). Ammonia inhibition in anaerobic digestion: A review. *Process Biochemistry*, *48*(5–6), 901–911. http://doi.org/10.1016/j.procbio.2013.04.012

CHAPTER 2: Paper 1 - World geography and power, national capitals, and inequality as cross-national causes of food security and environmental outcomes

Abstract

Treatments of sustainability outcomes such as food security, economic development and environmental degradation typically have adopted monocausal approaches. For instance, many have argued for substantial increases in world meat production as the panacea to global food insecurity. We use global and national synthetic explanations and a path analytic approach to examine sustainability outcomes for 218 nations during the modern period. We find strong direct or indirect links between global geography, global power and national capitals, as well as warfare and military expenditures, and a dependent variable of central focus to us, economic development. In turn these factors are differentially predictive of the other key measures of sustainability we attend to-- food sources, such as cereals and meat, which relate to food security and threats to the environment. We bemoan unrelated groups of research traditions that in their reductionist approaches are apt to miss the "big picture," of global and local, as well as direct and indirect connections that determine the singular but related outcomes that are so central to contemporary and future human life.

1. Introduction

According to the World Bank (Townsend et al. 2013) the world must produce "at least 50% more food to feed the 9 billion people" we expect to inhabit the planet by the year 2050. But even more alarming, World Bank analysts contend that climate change could further attenuate crop yields by more than 25%. Indeed, the world's natural capital in the form, among other things, of land, biodiversity, oceans, and forests are being depleted at unprecedented rates, while the magnitude of food insecurity is predicted to be substantially greater, especially for the poorer segments of the world's population, unless substantial changes are made in global food production and the structure and management of our natural capital.

While agriculture, in principle, can help reduce poverty for nearly 80% of the world's poor and substantially aid their food security through global agricultural adjustments that produce food locally and for the world market, the World Bank further warns that without appropriate action regarding global warming-- estimated to be on the path of a 4 degree C increase as we pass through the twenty- first century—we will counter hopes for agricultural productivity increases, leading instead to dangerous effects on agriculture generally, water resources, and on ecosystems and human health (Hallegatte et al. 2016). Every world region will be impacted, especially those least able to adapt, the already poor and vulnerable, which will be the hardest hit. Even 2 degree C and 1.5 degree C scenarios portend serious consequences. Thus, geographical dynamics will intimately affect food security around the globe.

Taken broadly, global and related national capital attributes also are key to food security and the related economic and environmental characteristics of nations; the FAO (FAO et al. 2014) appropriately focusses on the complex relationships among these factors. However, major international organizations have adopted approaches to global food security that are only partially in harmony with, and in some cases in contradistinction to, the relevant scientific literatures. As well, there are differences in findings reported among journal-length articles. Efforts to adjudicate these differences in vantage points are necessary. We conduct that exercise by way of a review of the major causal forces postulated in multiple literatures. We do so analytically by serially treating as causal forces, first, the role of natural capital in food security, indirectly, and then directly. Initially we consider the generic role of global Green Revolution and political economic forces in affecting national capitals. Then we consider the arguably significant role of more specifically identified perspectives, beginning with geographical and "mediating capitals" (which some refer to as "institutions") approaches to national development and food security. Then we address societal and global, as well as modernization and world-system approaches to food security. Our accompanying empirical treatment leads us to conclude that achieving food security involves global and national changes to a number of complex and interdependent causes drawn from the entire range of these substantive domains.

1.1. Foundational Issues

We begin with hunger and think it is important to address the historical context within which hunger in its many guises (such as food insecurity) has been debated and policies addressing it have emerged. This includes, especially, the Green Revolution. For instance, the leading plant biologist most often identified with developing hybridized seeds, Nobel Peace Prize winner, Norman Borlaug, asserts that global hunger is a result of declining or inadequate food production (Pilcher 2006). An important component of the Green Revolution and associated efforts included domestic modernization through agricultural industrialization in developing countries (McMichael 2004; Pilcher 2006). The Green Revolution also entailed other objectives more directly aimed at developing countries. These objectives included aims to raise farmer incomes, employ rural laborers, and feed the world's growing population (Altieri 1995; de Janvry 2010; Ehrlich et al. 1993; Uphoff 2002). Associated development strategies encompassed the implementation of centers for agricultural development, such as the Consultative Group on International Agricultural Research, which promoted an anti-poverty and anti-hunger agenda (Consultative Group on International Agricultural Research 2012). Was the Green Revolution less than successful in its mission? To be sure, there are equally compelling theorizations of hunger that assert global hunger instead is the result of inadequate access to resources, due to multiple causes ranging from comparative national geography, global power and dependency, inadequate national capitals (human, financial, political, infrastructural and military), inequality, and the nature of domestic agricultural systems. This reasoning strongly suggests that the problem of world hunger cannot be solved simply by augmented food production.

Consider, for example, Sen's (Sen 1981) analysis of the Bengali famine. Sen makes a strong case that famine and hunger emanate from personal and household economic and political vulnerability (Sen 1981; Sen 1997). Further, under the global food regime, newly agricultural countries have been increasingly competing in global food markets. Brazil and the growth in its soybean production is a prime example (Llambi 1993). Friedland (Friedland 2004) outlines the emergence of a new globalization in agriculture as the production of fresh produce for the permanently in-season market in the global North. Thus, an important factor contributing to the transformation of global agrarian structures is export production and concentration in high value commodities, such as fruits and vegetables. For globalization scholars, the global food regime marks the transition from a nationally-based Green Revolution that focuses on grains and basic food stuffs, to internationally-based global restructuring of agriculture that focuses on production for trade, thereby altering local agricultural production practices and outcomes (Bowen and Gerritsen 2007), including the plausibly greater food security otherwise associated with affordable domestic food consumption.

Food security issues similarly are under the control of sustainability dynamics such as national financial and environmental conditions. Many have argued that the dependency on chemicals and irrigation technologies and advancements in agriculture have created ecological problems—ranging from water pollution to soil salinization—that potentially may offset production gains (Altieri 1995; ALTIERI 2009; Jorgenson and Kuykendall 2008). Even if global grain production increased threefold in the latter part of the 20th century, fertilizer and pesticide use increased more than tenfold during the same period as a result of the spread of high-yield seed varieties and their associated production technologies (Jorgenson and Kuykendall 2008). Research on these transitions provides conclusive evidence that while the Green Revolution marks the most capital and chemically intensive structure of agricultural production in the history of humankind (Mazoyer and Roudart 2006), it has not eliminated the reliance on capital-intensive and ecologically destructive inputs (Buttel et al. 1985), and it has not eliminated global hunger. In summary form, proponents of Western-led national development, or modernization theorists that advocated for Green Revolution tenets, suggest that global agricultural production and trade improves human sustainability generally (Anonymous2008). On the other hand critics of the global capitalist system, namely political economists, posit that global agricultural production and trade is predicated on a system that exploits developing areas for the benefit of developed ones (e.g. (Burns, T., Kick, E., Davis,B. 2015; Friedmann 1982; McMichael 2004)). This casts the food security issue, as well as issues of finance and environment, in an entirely different light.

We consider these points of departure theoretically and empirically in more depth below. But we begin with a review of other related causal forces primarily postulated in the academic literature. These are centered on world geography and the condition of the many national capitals that (partly) flow from them, since it is these conditions that in many ways causally pre-date all others of primary interest here.

1.2. Geography, National Capitals and Food Security

Long ago Malthus (Malthus 1798) tied population growth to national physical calamities, with physical disasters and war culminating in widespread death from hunger. More recently, Sachs and Warner (Sachs and Warner 1995) and others have initiated significant discussion of the role of geography and related natural resources in aiding food security. For instance, it has been suggested that the geographic latitude of societies, reflected in locales such as tropical and desert spaces, are associated with a range of other domestic natural and human resources that adversely impact food security (Diamond 1997; Sachs and Warner 1995) and societal development. Few would question that Africa's geographical position hinders development (Bloom et al. 1998), insofar as it is characterized by the absence of fertile soils, and abundance of pests and parasites, hindrances to photosynthesis, frighteningly broad-based infection diseases, and even easily overlooked problematics such as the cost of transport from the interior to lucrative but distant markets (Sachs 2001; Bloom et al. 1998).

Consider as well the case of grains production elsewhere (Diamond 1997) compared with the alternative outputs of tropical areas. Diamond (Diamond 1997) contends that the lead established by areas on East-West geographic axes (e.g., Western and Eastern Europe, Eurasia) that grew grain species with a resistance to pathogens distanced them from other regions based on North-South or longitudinal axes (Latin America, Africa). The latter had comparatively little chance to compete. He continues his logic to include the presence and production of animal species that undergird superior relative production. As well, these species impact human disease, and by selective attrition, human capital leading to success in weaponry production and conquest by growing empires. Taken together these dynamics helped to ensure improvements in national well-being, including food security, for the Global North of Eurasia but the obverse for the Global South.

Easterly and Levine (Easterly and Levine 2002) in a related vein address endowment theory, which maintains that geographic dynamics shaped initial national capitals and that these forms of capital have had enduring repercussions on one another. However, Easterly and Levine add that despite their sharing of the same latitudes, there have been enormous capital changes as well as capital differences over time even in commonly situated tropical countries. They continue to suggest natural endowments impact economic development outcomes. Their endowments approach indicates that, among others, latitude differentials and access to the sea are significantly associated with national development. They empirically determine that net of controls, among others, natural resources, pathogens and crops, are more significant than tropical latitude (see Diamond (Diamond 1997)) or coastal access in explaining an index of multiple "capitals," as elaborated by Flora and Flora (Flora and Flora 2013), and as used here. These capitals include items such as human capital (education), infrastructural capital (buildings, roadways), political capital (democracy; political stability); economic capital (the gross domestic product), cultural capital (homogeneity in worldview and absence of warfare over it), and social capital (such as the absence of class divisions and commonality in goal attainment). Easterly and Levine's (Easterly and Levine 2002) seminal treatment suggests that natural endowments impact several capitals including economic development, consistent with the "geography hypothesis" which emphasizes endowments directly influence what has been termed "work effort" (Montesquieu, Charles de Secondat,baron de, 1689-1755. 1989) and agricultural productivity, which relates to the gross domestic product per capita (Myrdal 1968; Sachs 2001; Diamond 1997). Their findings are consistent too with the "institutions hypothesis" which argues endowments affect in an enduring way economic development and the resulting possibility of adequate food production.

However, in further regression analysis, although subject to some technical caveats (muticollinearity), Easterly and Levine (Easterly and Levine 2002) offer a crucial test that, as they put it, provides an "empirical sense" that the impact of institutional or capital development on economic development may be substantial, but such endowments do not explain economic development "beyond the ability of endowments to explain institutional development". Unfortunately, Easterly and Levine (Easterly and Levine 2002) leave us with the nettlesome question of how these forms of national capital relate to one another. It is important to know that national capital outperforms or translates geographic dynamics as an explanation of economic development, but if the capitals are equally influential in this role, is there an ordering among them that can be determined, in which certain capitals clearly bootstrap the others? This, too, is a key focus of our undertaking.

Romer (Romer 1989) and Lucas (Lucas 1988) clearly acknowledge that national capitals spur national development, and investment in infrastructural capital and human capital (education) could generally play a much greater role than is typically acknowledged. Putnam (Putnam 2000) has argued social institutions stimulate innovations, mutual learning, and productivity. Comparable arguments are forwarded by sociologists Coleman (Coleman 1986) and much earlier by Tonnies (Tonnies 1955) and Weber (Weber 2009). As North (North 1990) explains national institutions are "the underlying determinant of the long-run performance of economies."

For Rodrick (Rodrik 2007), economic capital spurs multiple interrelated capital investments under nuanced circumstances and it enhances the probability of equitable, that is, more equally distributed, gains from national productivity. For instance, the "design" of economic capitals depends upon the allocation of political power among elites, however, consolidated democracy is linked to favorable investment, thus the political drives the economic.

It can be argued as well that political capital develops in structures and economies where voice and accountability are established, as are practical stability, the absence of violence as well as effective governments, the non-interference of government and the rule of law. When taken together, these characteristics help ensure widespread access to societal well-being. It is the political apparatus that determines the allocation of society's resources, enhancing or limiting all of the other capitals. Insofar as political capital shapes the allocation process, it determines whether only a minority eat well or whether the population as a whole is served.

1.3. Societal and Global Approaches

Modernization theory, dating primarily from the early 1800s to the 1960s in the social sciences views development as the progression of a society's human values, culture, and technology. The Westernization of developing societies encompasses processes linked to advancement in the national capitals, offers a great deal of the logic foundational to the Green Revolution, and consequently is pertinent to economic development, food security, and the environment. Developed economies have the modern values, work ethics, superior technologies (Inkeles and Smith 1974; Rostow 1960) and most important, evolved capital institutions that are essential for development, broadly conceived. Early modernization theorists in particular considered Western nations as the blue-prints for how nations should industrialize and develop into modern societies, as seen in the work of Comte (Comte 1908; Smith [1776] 1994; Durkheim 1893; Ricardo 1819; Spencer 1887).

In more modern writings, Parsons (Parsons 1964) follows the evolutionary thinking of his forbears and proposes societies are comprised of significant capitals, conceptualized somewhat differently, that determine their progress: goal attainment, served by the capitals that set societal goals and objectives, partly to be achieved by success in the international arena in the acquisition, control and distribution of economic resources; integration, or value agreement achieved by coordination in society's courts, political systems (political capital) and agencies of social control (e.g., police and military); and latency, the maintenance of basic societal integration, fostered by the maintenance of cultural values and human capital. In economics, Rostow (Rostow 1960) proposed stages of societal growth through evolutionary stages – traditional; preconditions for take-off; take-off; and achievement of the ultimate stage of high mass consumption – all to be achieved through economic and infrastructural capital advance. For others, human capital attainments foster the advance that aids societal well-being, including environmental safety and related food security (Barro 1991). Indeed many focus on the importance of economic development to food security (Bullock and Firebaugh 1990; Jenkins and Scanlan 2001), and environmental risk (Neumayer 2013), while others focus instead on the determining role of modernizing political capital (Huntington 1968; Sørensen 1991).

Modernization of agriculture is a corresponding theme adopted by multilateral agencies during the Green Revolution era, and more recently by the World Bank's *World Development Report 2007* (World Bank 2008). Agricultural development theories have mirrored the transition from the development to globalization project (McMichael 2004) within the modernization theoretical camp. This includes the transition from a primary focus on agricultural technological development, such as in the early development of the Green Revolution technologies, to agricultural free-trade production strategies and, more recently, Bio-Revolution genetic technologies (Buttel et al. 1985; Pechlaner and Otero 2010). The basic premise of these approaches is that by adopting Western modernization capital technologies, and by industrializing their production in agriculture, national economies could develop, with consequent food production and food and environmental security. This has been extended to include export-oriented production strategies for development (Reid 2000).

1.4. Dependency and World-Systems Theories of Social and Economic Development

Political economy proponents counter many of the claims and findings of modernization scholars. Dependency writers (Prebisch 1948; SINGER 1949; Frank 1966) and world-systems theorists (Wallerstein 1974) focus on the inequitable power relationships among nations across the globe that result from exploitative production, trading, investment, and the overall structural positions of power and dependency of nations in the world division of labor. These processes are crucial to economy, food security and environment in all world sectors. According to Wallerstein (Wallerstein 1974) there is a three-tiered world system of core, semi-peripheral, and peripheral countries in which the core extracts surplus value from cheap labor and raw materials endemic to the periphery, and to a lesser degree the semi-periphery. This fosters nearly across-the-board advance for core countries. While it is less true for the semi-periphery, especially what we would term the "transitional" societies (e.g. India, China), the periphery in particular experiences under-development in its many forms (Amin 1976; Frank 1966). The capitals that the core may take for granted, political, economic, infrastructural, military and human capitals, for example, are vestigial and disarticulated from one another in the developing world. In turn, limited domestic capital formation and a malalignment among them limit the amount of "investment" that can go into social welfare, including investments to promote development, resulting in severe social problems including hunger (Baran 1957; Evans 1979; Chase-Dunn 1991) and the transfer of waste and other environmental maladies to the periphery, and to a lesser degree the semi-periphery (Foster 1999).

While many world-systems scholars emphasize the exploitative economic arrangements in the world order that benefit the core, other theorists within this tradition emphasize political arrangements, such as imperialism (Galtung 1971), that afford the core uneven global power and influence over peripheral nations. Indeed, political, economic and cultural and military processes together under-develop the non-core (Snyder and Kick 1979). It is especially noteworthy that the very nature of global agricultural production in the periphery undermines the developmental outcomes in these countries, jeopardizing universal food security, while simultaneously enabling luxury and excessive food consumption in the core (Shiva 2000). Some indicate that this has resulted in a "hunger/obesity paradox" (Dinour et al. 2007). Devereux (Devereux. Stephen 2007) reports that modern famines are a consequence of increased vulnerability due to globalization processes of integration and marginalization. Furthermore, as a result of dependency on food-imports, dependent economies are increasingly vulnerable to commodity price fluctuations. This vulnerability is heightened in severely marginalized regions, in particular sub-Saharan Africa, experiencing exceedingly high levels of poverty and political instability, which contribute to endemic hunger and famines (Devereux. Stephen 2007). Each of these new vulnerabilities due to globalization is further aggravated by transnational structures that cause peripheral nations to suffer the most extreme cases of hunger and “inherit” the environmental maladies of the core (Jorgenson and Kick 2006). Due to Westernization of the modernization process, sociological research views these circumstances as necessary to understand, in order to account for food security, economic stagnation and environmental maladies, both theoretically and empirically.

It is no surprise that political economists suggest that hunger, wealth and environmental degradation are best addressed through reducing both global and domestic inequality perpetuated by uneven structures of power and dependency across the world-system. All three are a matter of global and local structures that create distributional dynamics which cause the well-being of the Global North at the expense of the Global South.

2. Method of Analysis

2.1. Sample

To adjudicate the many complementary as well as contradictory themes reproduced above, we drew a sample of 218 nations from the over 200 countries that comprise the world. Excluded from our sample were small countries with populations of just a few thousand. Excluded also were countries that are not politically independent from another nations, and those that do not report conventional indicators to international organizations (e.g. North Korea). Our sample is larger than is typically the case in this study area, in part because our effort took relevant data from known sources that typically lead the world in breadth of data coverage (e.g. World Bank, FAO, UNESCO, SIPRI). We list the countries analyzed in Appendix A. We do not detect any easily discernible sample bias (except for the above), and believe our sample broadly represents all geographical areas in the world.

2.2. Analytic Technique

We use the special case of structural equation modeling, the well-established technique of path analysis (Wright 1921) to estimate models of the causal processes discussed above. The models estimated represent a web of variables with paths of origin, or independent variables, drawn to dependent variables--causation is shown in a variable's position as recipient of a path with an arrow head of causation pointing to it. Where possible we employed the more straight forward technique of using one measure for each variable of interest. In some cases we employed indexes comprised of variables represented by several latent measures of the construct of concern. In the latter case we gleaned from the literature the major variables treated as representative of the construct of interest. Tests were performed to ensure our constructs met the conditions prescribed by the ordinary least squares technique as described in Blalock (Blalock 1979) and in statistical programs such as SAS, SPSS, R and others. Our software of choice is SPSS.

Variables were causally connected by the theoretical expectations or hypotheses described above. No single researcher hypothesized the models tested, but each contributed hypotheses that we linked in order to create a "big picture" of the food security process. In so doing we were able to address related questions that formed a portion of the overall model. For example, we were able to treat a key question in the economics literature about whether economic development is a product of geography, one or more of the capitals, or a combination of geography and all the capitals in concert? Further we could address "will increasing meat and cereal production solve what many see as the serious problem of food security now and especially by the year 2050"? We also address probable sustainability consequences for the world as a whole of current solution sets.

2.3. Dependent Variables

We report results for the central food security dependent variable coded by the World Bank as the average daily intake of protein. We reason that the near parity in these numbers justifies the universal coding of our meat production and protein variables because the protein content of most meats is approximately the same (USDA 2016).

As a complementary dependent variable we use the Ecological Footprint as defined by Wankernagel and Rees (Wackernagel and Rees 1996). This dependent variable is the most commonly used indicator of the state of the international environment and measures both the biocapacity and ecological demands of nations. The ecological footprint captures key consumption-based activities that strain the environment across five primary economic sectors – energy, settlement, timber, food and fiber, and seafood. While we examined many alternatives for the environmental dependent variable, including nitrous oxide and grey water, the footprint offers robust validity in reporting and breadth in the availability of data. Other alternative measures were rejected because they often were confined to a marginal number of cases and subject to issues of recording and reporting difficulties. Moreover, they did not capture the central feature of our food security conceptualization, that consumption, rather than production, is the key to understanding food security in the world today. Thus by including an ecological indicator driven by consumption processes, we are able to capture the impact of agricultural production and consumption in our model.

Finally, consistent with the initial portion of our paper we place emphasis on a third leg of sustainability to complement our social and environmental measures--financial capital (Davis et al. 2012; Jenkins and Scanlan 2001). This variable, the national GDP/c (gross national product per capita) is the subject of vigorous debate as our earlier coverage of the literature suggests. We tried a number of other proxy measures too such as openness to trade, but found they were not “loading” satisfactorily in our exploratory factor analysis, or even if they marginally fit the financial capital construct, in combination with the GDP/c, the variable addition did not cause the measurement to respond in consistent ways or ways expected by the theoretical or empirical literature.

2.4. Independent Variables

2.4.1. Capital and its Forms

To examine earlier reported arguments we used measures of internal capital variables. Some researchers had principle interest in economic capital while others reported interest in causal relationships involving a wide variety of capitals. Capital as a term used in this paper refers to resources or assets. Often they are invested in their many forms to create new resources, frequently of a variety of new types, creating new capitals. We follow Flora and Flora (Flora and Flora 2013) in identifying seven capitals, and emphasizing six of them in our analyses. Most important initially to our treatment is “natural capital” that includes air, water, soil, biodiversity, weather, plant life, and other related items including those of high value such as oil. The literature identifies some forms of capital as assets and others as “curses.” Our hypothesis is in line with the former—natural capital in the form of eco-systems that are conducive to plant life (and therefore edible animal life) will aid all forms of sustainability.

Political capital permits social units of any size to translate its mores and norms into rules and regulations that enforce what has been referred to as the “social contract,” while distributing the pool of collective resources (gleaned e.g., from taxation) into many components that serve the collective good (highways, individual health, education and welfare (Parsons 1951). It determines the collective will on the distribution of resources and enacts that will. With this role political capital enhances democracy and stands as a central variable in subsequent advantage, determining the others, including economic capital. We are consequently following the lead of many who posit that political capital leads to economic capital and through a variety of other capitals effects food security and the environment (for discussion, see (Easterly and Levine 2002; Flora and Flora 2013; Weber 2009)). Our political capital variable is taken from the Worldwide Governance (WGI) projects which report country-level data for 1996 to circa the present on six dimensions of government: Voice and Accountability; Political Stability and Absence of Violence; Government Effectiveness; Regulatory Quality; the Rule of Law and, Control of Corruption (Worldbank 2014a).

Financial capital, in the words of Flora and Flora (Flora and Flora 2013) includes "savings, income generation, fees, loans and credit, gifts and philanthropy, taxes and tax exemptions. Financial capital is much more mobile than the other capitals and tends to be privileged because it is easy to measure." We commonly think of our incomes (or others') and collection of "riches" (wealth), but of course at the most collective levels these translate into national production income (the GDP/capita). The wealth per capita variable used is taken from the World Bank and log transformed to reduce skewness.

Infrastructural capital is built by humans for the purpose of collective living and goal attainment. Roadways, bridges, trains, planes and other conveyances are longstanding forms of infrastructure. In contemporary times it has increasingly become means of communication (such as cell phones) and other electronic forms for the achievement of the individual and collective wills. The infrastructure variable included an index of the number of fixed broadband internet subscribers per 1,000 people and passenger cars per 1,000 people (Worldbank 2000a; Worldbank 2000b). The data were compiled by the World Bank and accessed through their data portal; data used were circa 2000.

Military capital is a capital we add to the Floras' list. Military capital since World War II has become the critical mechanism used by states to achieve their national will using the real or the prospects for real coercive force. These may in the most crisis-filled times be employed to enforce the will of the state on segments of the nations' population. Typically, military capital has become institutionalized as a means to achieve national goals that either oppose the goals of other nations, or work in tandem with them. President Eisenhower identified a "military – industrial complex" in the U.S. that had come, in essence, to define and pursue their views of the goals of the nation, and impose them on the wills of citizens and opposing nations. A number of authors link military expenditures to well-being, facilitating employment and wages (Benoit 1973). We employ a measure of national expenditure per soldier taken from the World Bank (Military expenditures / Armed forces personnel) for circa 2000, as our military capital measure (Worldbank 2000c; Worldbank 2000d).

The GINI index measures wealth differentiations throughout the national system. Inequality scores range from a hypothetical “0” score (no inequality whatsoever) to a hypothetical “1” (the presence of total inequality in wealth distribution). The inequality data are taken from the World Bank (Worldbank 2000e) for the circa 2000 period.

2.4.2. Geographical Variables

We also used a geographical variable to represent earlier contentions in what might be called the “natural resources: blessing or curse” contention after the article by Sacks and Warner (Sachs and Warner 1995). We added coastal area, which measures in total kilometers the length of shoreline bordering a nation, and is taken from the World Resources Institute (World Resources Institute 2012). As an illustration, for the U.S. this primarily includes the combined lengths of the Atlantic and Pacific Oceans, and the Gulf of Mexico.

Eco-system capital is a continuous score assigned on the basis of the map of biomes or eco-systems as defined by the Museum of the University of California – Berkeley. Descriptions provided by that source and other comparable sources such as the University of Michigan, University of Missouri, and the National Geographic Society classification of biomes as operationalized by growing conditions, plant life, soil composition etc., were used to rank order on an ordinal scale those eco-systems most conducive to the production of plant and animal life. Our scores range from “1” assigned to the least productive (e.g., desert), “2” for the next to least productive (e.g. tropical rainforest and savannah) and “3” for the most productive biomes (e.g., temperate forest, grasslands, and taiga).

Finally, we include a measure of the latitude for each country to capture the essence of Diamond’s (Diamond 1997) argument about the importance of a society’s latitude for its ultimate well – being. Recall Diamond emphasizes the geographical advantages of the East-West axes characteristic of the Northern latitudes.

2.4.3. Other Independent Variables

We also included a conflict variable based on earlier arguments and the intuitive understanding that protracted internal wars may disorganize critical forms of capital and rob them of necessary monetary support. For example, warfare may take human capital that would be more optimally employed in other national sectors. It likely will disrupt internal production including crucial food production, destroy otherwise productive land and, until resolved successfully, even stand in the way of an evolving national identity based on cultural legacies (Flora and Flora 2013). Our source relies on SIPRI (Stockholm Peace Research Institute) and war data reported by Sivard (Sivard 1996). Ultimately global news reporting agencies (the BBC, the NY Times) provide on – site conflict accounts that frequently corroborate second-level sources. While wars in modern times typically occur on the soils of developing countries, forty-six instances during the period examined involved the military interventions of the powers of the Global North.

We use a variable measuring the centrality of a nation in the international arena, or its world system position. The data involve matrices of nation-to-nation multiple networks – economic trade, military exports, the existence of embassies from foreign countries on host soils, and political treaties (a symmetric matrix) for the years 1995-1999 — which identify the degree of centrality of each nation vis-a-vis all others in the global political economy. Their centrality and power/dependency is demonstrated through the application of a "multiple-network analysis" ("blockmodel") program that simultaneously analyzes the structural positionality across the four networks for each nation. The results show which nations cluster into similar structural positions insofar as they are similarly related to all other nations across all four dimensions of connectivity. The software to produce the final results is from UCINET from the University of California. An early discussion describing the technique is found in Snyder and Kick (Snyder and Kick 1979) and the exact country classifications are provided in (Kick et al. 2011). For illustrative purposes we mention the United States stands as the head of the "core" of the world system in the results, joined by Japan and the bulk of Western Europe, Australia and Canada. The periphery is comprised of the bulk of the so-called "developing world" of South East Asia, Africa and Latin America. Between these extremes are the semi-peripheral nations of Eastern Europe, the rapidly rising nations of India and China, and several larger oil-producing countries. These tripartite distinctions correspond with Wallerstein's (Wallerstein 1974) world – systems approach as discussed above.

Our treatment of societal food production is the production of crops and meat available in principle for consumption by the national population. Total crop production is defined as the total food crops produced in a year that are edible and contain nutrients; thus, coffee and tea are excluded due to its lack of nutrients value (Worldbank 2005a). Livestock production is defined as the total livestock produced in a year (in tons) that includes meat and milk from all sources, dairy products and eggs, honey, raw silk, wool, and hides and skins (Worldbank 2005b). The data were compiled by the World Bank and accessed through their data portal; data used were circa 2005. Our assumption, however, is that despite these changes to overall available domestic food, it is the absence of wages to purchase food produced internally or imported externally that is the principal limit placed on food security for poor countries. This limit is reflected in the GINI which measures the distribution of wealth. Certainly as described food sources are fostered by the domestic production of meat, crops and the available wealth (GDP/c) to purchase them, as well as by other dynamics discussed earlier that facilitate domestic production on smaller farms. Also, while food is imported for the population, some unknown portion is often "pirated" by officials in government positions or common robbers in the distribution system, who may garner, hoard, and sell a variety of foodstuffs.

3. Results and Discussion

Figure 1 presents the path model for the estimated links between geographic and global system precursors to the various national capitals, and the capitals' effects on economic development.

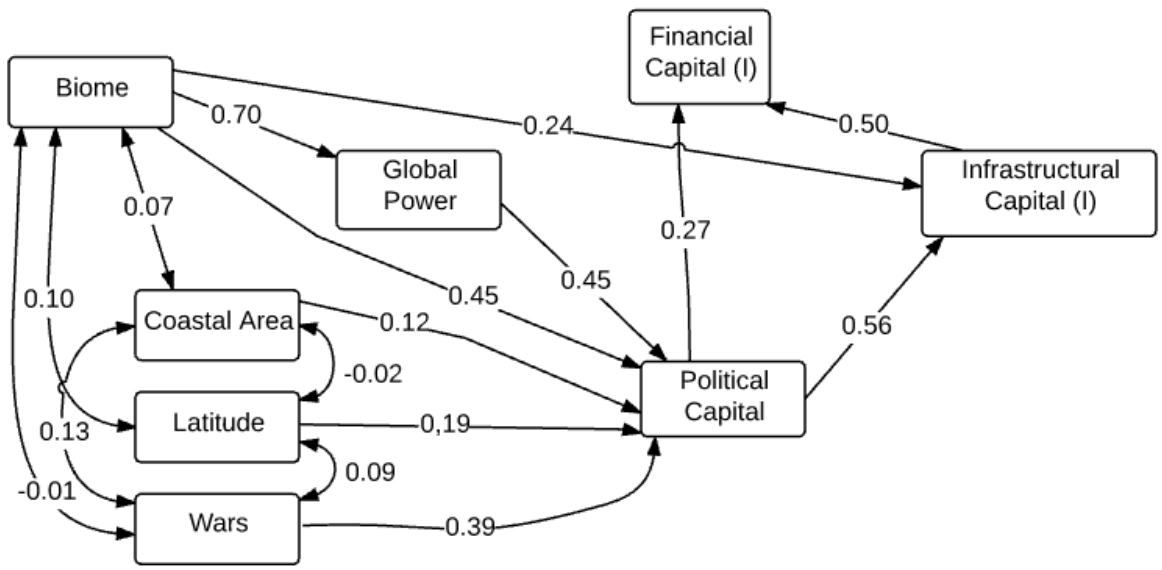

Figure 1. Geography, capitals, and economic development. The numbers on each path are statistically significant standarized coefficients representing the impacts of the causal variables on the caused variables. Per standard SEM estimating procedures, error terms were included for all endogenous variables across both models.

Information supporting the beta coefficients presented on paths between causal and caused variables is offered in the Appendix B (e.g., means, standard deviations, correlations). Only paths of statistical significance are presented, although a sizeable number were estimated.

The readers' attention is drawn to the strong pathway between national eco-systems (Biome) and their global power and global powers' moderately strong impact on political capital, and the favorable economic returns (financial capital) to political capital. To be sure, latitude and size of coastal boundaries also impact the political capital index, consistent with the East-West axes themes developed by Diamond (Diamond 1997), and with others who emphasize the criticality of the seas to national trade, conquest, and power as well, especially the world systems theorists (Wallerstein 1974). When considered historically, this helps interpret the experiences of Western Europe in particular. The Western European countries enjoyed the advantages of natural resources that are part of their well-endowed eco-systems. These included the availability of food and housing potentials, and advantages in the construction of the machinery and weaponry of conquest. The national biome influences domestic infrastructure directly while the latitude works indirectly through political capital to influence infrastructure; payoffs to infrastructure will be considered when Figure 2 is examined. Aside from geography, wars could in principle weaken the political capital and overall well-being of a nation. This is particularly true in the Global South where political capital is already weak. Nevertheless, the pathways of Figure 1 also reflect the involvement in wars of the Global North (with its stronger political capital) in its interventions into the Global South.

Notable results from Figure 1 are the powerful effects documented for geographic inputs, which commonly are ignored in studies of national development. Notable as well is the explanatory consequences of geography for domestic capitals (political and financial) and for international capital in the form of global centrality and power of nations. There is little question this feeds back into the domestic system as global prominence enhances domestic well-being.

Figure 2 relationships link these factors to food security as well as to ecological consequences. Economic development is directly tied to the national infrastructure. The huge effect of the gross national product per capita on the Gini index of inequality is especially worthy of attention. This finding is far from unusual, although the strength of the relationship for the contemporary period is surprising. One plausible explanation is that typically the strong relationship between national wealth and greater inequality is most manifest as transitional societies grow in population. The modern period has been characterized by this dynamic, and it apparently has included the emergence of significant surpluses that are especially mal-distributed. In relative terms there plausibly is much greater equalization among wealthier nations, even if that equalization is among classes below the wealthiest ones.

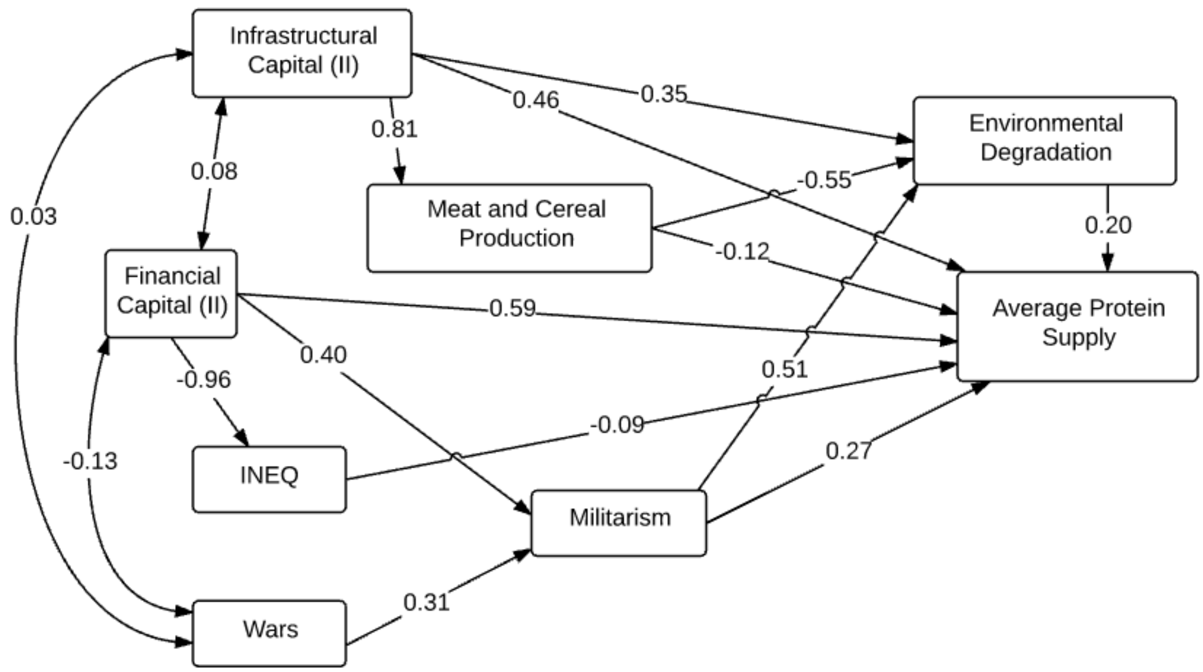

Figure 2. Economic development, infrastructure, militarism, food production and security. The numbers on each path are statistically significant standardized coefficients representing the impact of the causal variables on the caused variables. Per standard SEM estimating procedures, error terms were included for all endogenous variables across both models.

National wealth would seem likely to improve the national power to produce high protein foods, however it does not improve protein-related food security through the route of meat and cereal production. Meat and cereal production require a certain degree of infrastructural development, and this is confirmed in the coefficient between infrastructural capital and total meat and cereal production. All of these trends are shown in Figure 2. Infrastructural usage or improvements of virtually any sort should increase the ecological footprint, insofar as the infrastructure facilitates production and transportation of products and often does so with a high profile usage of fossil fuels. As well, the components leading to the consumption process are made possible by infrastructure and the energy needed to run it and by the forms of waste it creates as well. By the same logic the impact of expenditures on the national military apparatus, a logical consequence of warfare, appear likely to augment energy production, waste generation, and the concomitant CO_2–dominated footprint. In a related vein, as might be anticipated, wars exacerbate state expenditures on the military by a considerable margin, and the development of the military complex results in infrastructural benefits, likely in the form of equipment for soldiers and related developments such as the growth in military installations, armament industries, and related offshoot technological industries are either expanded or created anew.

Relative to industrial production, it appears that agricultural production and waste is less pernicious in its footprint consequences. This is not to say that agricultural production is void of impact on the environment. Production and use of pesticides, fertilizers, and machinery ensure that agriculture leaves its imprint on the Earth. Yet its footprint remains trivial in the CO_2-dominated measurement of the ecological footprint, relative to industrialization in all other sectors of the economy combined.

The footprint marginally is related to the protein supply. It seems most possible that wealth and infrastructure that increase the footprint also contribute to commercial sources of the food.

4. Conclusions

We began with the conviction of the World Bank that the nations of the world must produce substantially more food in order to feed the 9 billion people expected to inhabit our planet by the year 2050. We also observed that environmental degradation is likely to exacerbate this problem, while creating a plethora of other concerns in its own right. Furthermore, at present, we face economic reversals that bring concern to virtually all sectors of the world. While some optimistically posit that technological fixes will remedy all these sustainability issues, other more pessimistically question the nature of the global structure, both geographically and in its socio-economic manifestations, as forces responsible for the troublesome futures facing all of humanity. Within these generic and oppositional frameworks we offer a series of perspectives for analysis and evidence that essentially corroborates one interpretation or the other, suggesting a more grand systematic approach be undertaken.

One school of thought emphasizes geographical preconditions as the key factors that are driving past and current national food security, levels of economic well-being, and the variety of national (and global) environmental circumstances that threaten the world's future. What does our empirical assessment suggest? Our path analysis of 218 countries shows there is notable validity to such arguments. The eco-system conditions of nations affect the economic trajectories of nations by direct and indirect pathways. Biomes' direct impact on national wealth is trivial. However, its influence is substantial when considered indirectly, through the international strength of states, which helps ensure state strength and thereby economic well-being. Further, superior geographical circumstances permit the accumulation of substantial surplus that induces strong states (political capital) and competitive economic systems. To be sure, the latitudes of countries contribute to the biomic characteristics of countries, however the relationship between latitudes and biomes is far from linear and is filled with anomalies. For example, the countries of Eurasia share approximately the same latitude, though not biomes, and these countries differ substantially in their economic strength, state viability, and environmental circumstances. Diamond's (Diamond 1997) early treatment of such issues appears to emphasize the near sole importance of east-west versus north-south axes, and consequently latitudes. Yet, his argument is a great deal more nuanced and includes biomic considerations. Put differently, perhaps due to his own emphases, but also likely due to the need of reading audiences to simplify, the many other geographical precursors to economic well-being in Diamond's work commonly are secondary in treatment of his work. Our results document the need for future research to pay a great deal more attention than has been the case in the past to the eco-systems of nations, and to recognizing the heterogeneity of eco-systems within nations in order to understand economic development. The United States, for example has some of their most productive lands (such as Indiana, Illinois, Iowa, and Kansas) at approximately the same latitude as the least productive (such as Nevada, Utah, and parts of Wyoming). It also has some of the driest areas (southern parts of Arizona and New Mexico) at the same latitude as some of the wettest areas (Louisiana, Mississippi, and Georgia). Similarly, the most productive agricultural areas of Europe are at the same latitude as those areas of eastern Canada with much more limited agricultural options.

It is common for studies in Sociology to report strong, direct linkages between the structural positons of the power of nations and consequent national economic development and growth, as well as inequality. For the contemporary period tapped by our data however, we found world power vis-à-vis other nations predicted to national state strength or political capital, which in turn determined economic development. This finding is different from emphases adopted in a number of prior treatments. After some reflection we realized that we had never before seen an estimation that employed state strength as a mediating variable translating the effect of global power on a range of domestic outcomes, including economic capital! We could only recollect estimations of direct effects between world-system position and economic development. It is plausible that Wallerstein's (Wallerstein 1974) popular and pioneering approach to the world system was a Marxian- inspired approach which established a legacy that seemingly ignored the possibility of a nation state translating its international power to significant domestic capital advantage, which then was converted to economic advantage. Once we seriously considered the matter, a series of possible mechanisms became obvious, from the state's collection of taxes and determination of domestic usage of those revenues, to the setting of landownership rules and regulations, to the state's coalitional powers with giant multinationals, and in the modern era, its power to dole out support to portions of the corporate world and the public to keep them afloat during the most challenging of times. By so doing, the wealthiest of states at least have avoided or postponed cataclysmic national economic consequences.

Do geographic effects operate through domestic capitals to impact economic development? Our results suggest they surely do. Domestic capitals are important in their own right, but in a sense, they often translate geographic factors into a range of outcomes, including those that are economic in nature. For us, the interaction of the two domains and their consequences is an absolute necessity for future empirical examination.

Put another way, we find strong support for synthetic interpretations in Figure 1. We do as well in Model 2 results. Modernization and related Green Revolution policies of the earthly system offer optimistic interpretations that with technological know-how and the transmission of Westernization and its accompanying technology to the Global South, it too could enjoy the advantages of sustainability enjoyed by its powerful counterparts. Our generic Model 2 reinforces modernization themes that technological advance shown in infrastructural strength pays off in greatly augmented meat and cereal production. Infrastructural improvements are commonly accompanied by wealth enhancements, although the linkages demonstrated here are far from powerfully demonstrated (correlation is +0.08). Fortunately, wealth reduces domestic warfare as anticipated, which would appear fortunate because warfare increases national expenditures on the military apparatus—referred too pessimistically as the "military-industrial complex" by President Eisenhower. Yet, whether it is due to a sort of Keynesian militarism or not, the empirical linkages demonstrated in earlier studies showing the military helps poor farmers in settings across the world (Nigeria, China) are shown here too. These indirect ties indicate that the military helps ensure the population is fed in both the Global North and South. Many will not find this a popular finding. Nonetheless, during the most recent period it has served this function. We emphasize "most recent period" because we are not sure if these causal connections have applied throughout historical time. It could be the case that during global downturns military Keynesianism yields some positive results that it might not during other periods of time.

The whooping negative effect of economic development on the Gini was not entirely expected. Certainly after a point, the modernists argue, development will help ensure the equalization of wealth distribution. We raise the possibility however, that popular movements around the world have challenged governments to respond with democracy and more equity in the sharing of wealth. To be sure global economic downturn has brought with it an equalization in the wealth of the so called middle and lower classes, but news agencies are rife with reports of the sharp concentration of wealth in the hands of the few (Amnesty International). Arguably, then, we are witnessing a convergence in the wealth of all classes except the very wealthiest, who have distanced themselves further from the rest while being substantially reduced in size. This is an important empirical question that requires an in-depth answer that is well beyond the scope of our effort.

Our central concern has been with the impact of technological processes and modernization, as well as world-system dynamics, on the production of food and the likely state of the masses in the year 2050. Relative to one another, developed countries can be expected to be the locus of well-fed populations, but the same cannot be said of the Global South (correlation is +0.59). This effect is quite notable and points to a divergence, not a convergence, in the future hunger profile of the world due to a widening of the income gap between rich and poor of the world. While some have proposed a near global wealth and wellbeing increase in the offing for the future and an apparent evaporation of the income gap between rich and poor except for the deeply distressed continent of Africa, World Bank data show the opposite. Some transitional societies have made surprising strides in recent years, although those national profiles do not reveal the vast differences in regional distributions of wealth within the same nation (e.g., coastal versus rural China). However, even the most cursory examination of modern World Bank data show that the bulk of Africa at this time is around $1000 GDP/c or lower, the next band of developing nations clusters between $1000 and $2500 annual GDP/c, while Western Europe has an approximate average of around $50,000 per annum and the United States has an average of around $55,000 per annum (Worldbank 2014b). Rates of annual growth in the Global South may be somewhat higher than in the Global North—but it is doubtful convergence will stem from slightly higher growth rates and phenomenally different bases! Three decades ago the wealth gaps between nations were within $20,000 of one another. By 2050 there may be a convergence among those at the bottom of the global distribution, among some transitional societies, and among the wealthiest, but divergence will be the character of the gap among the highest and lowest sectors of the distribution.

The above analysis confirms the adage, 'the rich will get (relatively) richer and the poor will get (relatively) poorer.' As we raise the possibility that this will be true in the comparison between Northern and Southern nations and within them as well, we ask: can the current gap be largely offset by technological innovations and the production of greater cereal and meat quantities, as suggested by the World Bank? On the basis of our analyses, the food security gap cannot be reduced by 2050, not because of insufficient technology and global food production but because of inadequate wealth distribution within countries and the concomitant inability to purchase sufficient food locally.

Immediately worth consideration is the negative effect of the GINI coefficient of inequality on average protein supply per capita. Even if the production of food increases, the arguments presented above about global power and the negative effect of the GINI coefficient suggest that to some degree wages will continue to be mal-distributed in the developing world, and without greater wage and wealth equalization true food security may be out of reach for some significant segment of the world's population.

Further, and even more troublesome, we find a relatively small but NEGATIVE relationship between meat and cereal production and the average daily intake of protein. How is this to be understood? Arguably food waste, and even more so maldistribution by the state and elites will impair the average protein intake of the masses. Further, domestic production may increasingly be destined for export by agribusiness. The production of food does not bear a one-to-one relationship with the consumption of food. World-system and dependency authors argued early on that the Global South's production of food was "distorted" bringing profits to local elites in alliance with foreign powers, much to the detriment of farm workers or peasants (Prebisch 1948; SINGER 1949; Frank 1966). Further still, modernization programs for the infrastructural development of poorly developed countries may foster the production or import of food but are based on the techniques and preferences of the Global North. Imported farm machinery may require repairs that are not readily available and require long-delayed importation of parts from distant spaces. In addition, techniques of planting, fertilizing, pesticide application, and the availability of water may be based on templates that are taken-for-granted in developed countries but are not part of the cultural legacy of developing nations.

Agriculture, represented here by meat and cereal production, converts solar energy and atmospheric CO_2 into human food. Modern agricultural practices can also contribute harmful emissions of methane and nitrous oxide (European Commission Joint Research Centre 2016; NASA 2010; Walsh et al. 2009), both of which are strong greenhouse gases. The ecological footprint that was used to represent the ecological degradation variable only includes CO_2 emissions; it specifically does not include methane and nitrous oxide (Borucke et al. 2013; Walsh et al. 2009). The moderately strong but negative effect of meat and cereal production on (-0.12, Figure 2) reflects the conversion of atmospheric CO_2 by crop production while ignoring the very real environmental consequences of these other emissions. If either or both of these gases were incorporated into the footprint calculation as Walsh demonstrated with methane (Walsh et al. 2009), the footprint estimates around the world would in all probability be very different, leading to very different conclusions.

Thus we are not sanguine about an improved global environment by 2050 either. Virtually all theorizations on the environment assume that the coalition, or even multiplication of population, wealth, and technology (such as that shown in the direction taken worldwide in wars and militarism) will continue to drive the world environment in a negative direction for the more immediate future (McMichael 2004; Burns, T., Kick, E., Davis,B. 2015; Easterly and Levine 2002; Jorgenson and Kick 2006). The natural resources that bootstrap political, financial, and infrastructural capitals and economic development in all probability will advance societal and global expansion and, according to our results, will indirectly drive the system toward greater environmental degradation with its attendant hazards. Although the environment has not been a central concern of this manuscript, we note its importance and fear it too will impact food security in a pernicious manner, even if it does not appear to do so through the footprint variable in our model here. While controversial, most who scientifically study the environment share our fears, albeit for a variety of reasons. We reiterate that it too must be viewed as part of an interdependent system along with the other dynamics we have considered. Consequently we urge it be considered scientifically in those terms as well. In an age of scientific specialization, we hope for even more interdisciplinary work that treats the global order with broad strokes and assesses the interdependence of the natural order of things.

Not tested in our analysis is the validity and expected effectiveness in world programs for meeting the expected demands for a growing population of the explicit assumption that any increase in the world population will demand food that reflect the typical Western diet centered on meat and meat products. Popular data on food preferences also show vast differences between Western Europe and the US and the countries of Latin America, Africa, and South-east Asia. While meat assumes a position of priority in the diets of Western Europe and the United States. While meat products (e.g., milk) are valued in the Global South, its consumption of meat is far lower than that of the Global North. Africans or portions of Africa appear to more highly value yams, plantains, green bananas, barley, black- eyed beans, curry, eggplant and lentils. It could be that if the Global South were only richer they would purchase the meat and cereals enjoyed by the Global North with their newfound wealth. It could also be true that the provision of meat and cereals that are not routinely part of the diets of third world citizens will go uneaten. The actual preferences and culinary culture of people around the world should be examined before vast resources are devoted to the infrastructure necessary to recreate Western diets for the entire world. The health implications and the associated financial and human costs of those diets should also be investigated.

References

2009 List of Developing Countries. 2008.Washington, D.C.: World Bank.

ALTIERI, M. A. 2009. Agroecology, Small Farms, and Food Sovereignty. Monthly Review: An Independent Socialist Magazine 61(3): 102-113.

Altieri, M. A. 1995. Agroecology : the science of sustainable agriculture. Boulder, Colo.; London: Westview Press; IT Publications.

Amin, S. 1976. Unequal development: An essay on the formation of peripheral capitalism. Monthly Review: An Independent Socialist Magazine(6): .

Baran, P. A. 1957. The political economy of growth. New York, Monthly Review.

Barro, R. J. 1991. Economic Growth in a Cross Section of Countries. The Quarterly Journal of Economics 106(2): 407-443.

Benoit, E. 1973. Defense and Economic Growth in Developing Countries. Washington, D.C.: Health Lexington Books.

Blalock, H. M. 1979. Social statistics. Revised 2nd ed ed. New York: McGraw-Hill.

Bloom, D. E., J. D. Sachs, P. Collier and C. Udry. 1998. Geography, Demography, and Economic Growth in Africa. Brookings Papers on Economic Activity 1998(2): 207-295.

Borucke, M., D. Moore, G. Cranston, K. Gracey, K. Iha, J. Larson, E. Lazarus, J. C. Morales, M. Wackernagel and A. Galli. 2013. Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. Ecological Indicators 24518-533.

Bowen, S. and P. Gerritsen. 2007. Reverse leasing and power dynamics among blue agave farmers in western Mexico. *Agriculture and Human Values* 24(4): 473-488.

Bullock, B. and G. Firebaugh. 1990. Guns and butter? The effect of militarization on economic and social development in the Third World. *Journal of Political and Military Sociology* 18231-266.

Burns, T., Kick, E., Davis,B. 2015. Theorizing and Rethinking Linkages Between the Natural Environment and the Modern World-System: Deforestation in the Late 20th Century. *Journal of World-Systems Research* 9(2): 357-390.

Buttel, F. H., M. Kenney and J. Kloppenburg. 1985. From Green Revolution to Biorevolution: Some Observations on the Changing Technological Bases of Economic Transformation in the Third World. *Economic Development and Cultural Change* 34(1): 31-55.

Chase-Dunn, C. 1991. *Global formation : structures of the world-economy.* Cambridge, Mass.: Basil Blackwell.

Coleman, J. S. 1986. Social Theory, Social Research, and a Theory of Action. *American Journal of Sociology* 91(6): 1309-1335.

Comte, A. 1908. *A general view of positivism.* London, Routledge, 1908.

Consultative Group on International Agricultural Research. 2012. The CGIAR at 40 and Beyond: Impacts that Matter for the Poor and the Planet. Available at: http://www.cgiar.org/pdf/cgiar@40_final_LOWRES.pdf. Accessed December 10 2015.

Davis, A. S., J. D. Hill, C. A. Chase, A. M. Johanns and M. Liebman. 2012. Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health. *PLoS ONE* 7(10): 1-8.

de Janvry, A. 2010. Agriculture for development: new paradigm and options for success. *Agricultural Economics* 4117-36.

Devereux. Stephen. 2007. From 'Old Famines' to 'New Famines. In *The new famines: why famines persist in an era of globalization,* 367. ed. edited by Devereux. Stephen, London ; New York: Routledge.

Diamond, J. M. 1997. *Guns, germs, and steel : the fates of human societies.* New York: W.W. Norton & Co.

Dinour, L. M., D. Bergen and M. Yeh. 2007. The Food Insecurity–Obesity Paradox: A Review of the Literature and the Role Food Stamps May Play. *Journal of the American Dietetic Association* 107(11): 1952-1961.

Durkheim, É. 1893. *The division of labor in society.* New York: Free Press, 1997.

Easterly, W. and R. Levine. 2002. How Ecological Endowments Condition Economic Development. *National Bureau of Economic Research working paper series;* http://www.nber.org/papers/w9106.pdf January 23, 2016.

Ehrlich, P. R., A. H. Ehrlich and G. C. Daily. 1993. Food Security, Population and Environment. *Population and Development Review* 19(1): 1-32.

European Commission Joint Research Centre. 2016. Emission Database for Global Atmospheric Research: Nitrous Oxide. Available at: http://edgar.jrc.ec.europa.eu/part_N2O.php. Accessed 04/09 2016.

Evans, P. B. 1979. *Dependent development : the alliance of multinational, state, and local capital in Brazil.* Princeton, N.J.: Princeton University Press.

FAO, IFAD and WFP. 2014. *The State of Food Insecurity in the World 2014. Strengthening the enabling environment for food security and nutrition.* Rome: FAO.

Flora, C. B. and J. L. Flora. 2013. *Rural communities: legacy and change.* 4th ed ed. Boulder, Colorado.: Westview Press.

Foster, J. B. 1999. Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology. *American Journal of Sociology* 105(2): 366-405.

Frank, A. G. 1966. The development of underdevelopment. *Monthly Review: An Independent Socialist Magazine* 18(1): 17-31.

Friedland, W. 2004. Agrifood Globalization and Commodity Systems. *International Journal of Sociology of Agriculture and Food* 125-16.

Friedmann, H. 1982. The Political Economy of Food: The Rise and Fall of the Postwar International Food Order. *American Journal of Sociology* 88S248-S286.

Galtung, J. 1971. A Structural Theory of Imperialism. *Journal of Peace Research* 8(2): 81-117.

Hallegatte, S., M. Bangalore, L. Bonzanigo, M. Fay, T. Kane, U. Narloch, J. Rozenberg, D. Treguer and A. Vogt-Schilb. 2016. Shock Waves: Managing the Impacts of Climate Change on Poverty. *World Bank.*

Huntington, S. P. 1968. *Political order in changing societies,* New Haven, Yale University Press, 1968.

Inkeles, A. and D. H. Smith. 1974. *Becoming modern: individual change in six developing countries.* Cambridge, Mass.: Harvard University Press.

Jenkins, J. C. and S. J. Scanlan. 2001. Food Security in Less Developed Countries, 1970 to 1990. *American Sociological Review* 66(5): 718-744.

Jorgenson, A. K. and K. A. Kuykendall. 2008. Globalization, Foreign Investment Dependence and Agriculture Production: Pesticide and Fertilizer Use in Less-developed Countries, 1990-2000. *Social Forces* 87(1): 529-560.

Jorgenson, A. K. and E. L. Kick, eds. 2006. *Globalization and the environment.* Leiden; Boston: Brill.

Kick, E. L., L. Mckinney, S. McDonald and A. Jorgenson. 2011. A Multiple-Network Analysis of the World-System of Nations. In *The Sage Handbook of Social Network Analysis,* 311-328. ed. J. Scott and Carrington, P., London: Sage.

Llambi, L. 1993. Global agro-food restructuring: The role of transnational corporations and nation states. *International Journal of Sociology of Agriculture and Food* 319-39.

Lucas, R. E. 1988. On the mechanics of economic development. *Journal of Monetary Economics* 22(1): 3-42.

Malthus, T. R. 1798. *An essay on the Principle of Population.* London: Oxford University Press.

Mazoyer, M. and L. Roudart. 2006. *A history of world agriculture: from the neolithic age to the current crisis.* New York: Monthly Review Press.

McMichael, P. 2004. *Development and social change: a global perspective.* Thousand Oaks, CA: Pine Forge Press.

Montesquieu, Charles de Second, 1689-1755. 1989. *The spirit of the laws.* Cambridge; New York: Cambridge University Press.

Myrdal, G., 1898-1987. 1968. *Asian drama; an inquiry into the poverty of nations.* New York, Pantheon 1968].

NASA. 2010. Education: Global Methane Inventory. Available at: http://icp.giss.nasa.gov/education/methane/intro/cycle.html. Accessed 04/09 2016.

Neumayer, E. 2013. *Weak versus strong sustainability : exploring the limits of two opposing paradigms.* 4th ed. Cheltenham Glos, Uk: Edward Elgar Publishing, Ltd.

North, D. 1990. *Institutions, Institutional Change, and Economic Performance.* Cambridge, UK: Cambridge University Press.

Parsons, T. 1964. *Social structure and personality.* New York: Free Press of Glencoe.

Parsons, T. 1951. *The Social System.* Glencoe, Il: Free Press.

Pechlaner, G. and G. Otero. 2010. The Neoliberal Food Regime: Neoregulation and the New Division of Labor in North America. *Rural Sociology* 75(2): 179-208.

Pilcher, J. M. 2006. *Food in world history.* New York, NY: Routledge.

Prebisch, R. 1948. Acerca de los anteproyectos sobre Banco Central y bancos. *Revista de hacienda* 13146-178.

Putnam, R. D. 2000. *Bowling alone: the collapse and revival of American community.* New York: Touchstone, 2001.

Reid, G. 2000. Free trade, business strategy and globalisation. *Global Business and Economics Review* 2(1): 26-38.

Ricardo, D. 1819. *On the principles of political economy and taxation/ y David Ricardo electronic resource].* Georgetown, D.C.: Joseph Milligan, 1819 (Washington City : Jacob Gideon.

Rodrik, D. 2007. *One economics, many recipes : globalization, institutions, and economic growth.* Princeton: Princeton University Press.

Romer, P. 1989. Endogenous Technological Change. *National Bureau of Economic Research working paper series;* NBER Working Paper No. 3210.

Rostow, W. W. (. 1960. *The stages of economic growth, a non-Communist manifesto.* Cambridge Eng.] University Press, 1960.

Sachs, J. and A. Warner. 1995. Natural resource abundance and economic growth. Working Paper 5398.

Sachs, J. 2001. *Tropical underdevelopment, Working Paper 8119.* Cambridge, MA.: National Bureau of Economic Research.

Sen, A. 1997. Hunger in the Contemporary World. Development Economics Discussion Paper No. 824.

Sen, A. 1981. *Poverty and famines : an essay on entitlement and deprivation.* Oxford; New York: Clarendon Press; Oxford University Press.

Shiva, V. 2000. *Stolen harvest : the hijacking of the global food supply.* Cambridge, MA: South End Press.

SINGER, H. W. 1949. ECONOMIC PROGRESS IN UNDERDEVELOPED COUNTRIES. *Social Research* 16(1): 1-11.

Sivard, R. L. 1996. *World Military and Social Expenditures.* Ann Arbor, MI: Inter-university Consortium for Political and Social Research 1996.

Smith, A. [1776] 1994. *An inquiry into the nature and causes of the wealth of nations.* New York: Modern Library.

Snyder, D. and E. L. Kick. 1979. Structural Position in the World System and Economic Growth, 1955-1970: A Multiple-Network Analysis of Transnational Interactions. *American Journal of Sociology* 84(5): 1096-1126.

Sørensen, G. 1991. *Democracy, dictatorship and development: economic development in selected regimes of the third world.* Houndmills, Basingstoke, Hampshire: MacMillan.

Spencer, H. 1887. *The factors of organic evolution.* London: Williams and Norgate.

Tonnies, F. [. 1955. *Community and Association (Gemeinschaft und gesellschaft).* London: Routledge and Kegan Paul.

Townsend, R., I. Ceccacci, S. Cooke, M. Constantine and G. Moses. 2013. *Implementing agriculture for development : World Bank Group agriculture action plan (2013-2015).* Washinton DC: World Bank.

Uphoff, N. 2002. *Agroecological innovations: increasing food production with participatory development.* London ; Sterling, VA: Earthscan Publications.

USDA. 2016. All About the Protein Food Group. Available at: http://www.choosemyplate.gov/protein-foods. Accessed 04/09 2016.

Wackernagel, M. and W. E. Rees. 1996. *Our ecological footprint : reducing human impact on the earth.* Gabriola Island, BC ;Philadelphia, PA: New Society Publishers.

Wallerstein, I. M. 1974. *The modern world-system; capitalist agriculture and the origins of the European world-economy in the sixteenth century.* New York, Academic Press.

Walsh, C., B. O'Regan and R. Moles. 2009. Incorporating methane into ecological footprint analysis: A case study of Ireland. *Ecological Economics* 68(7): 1952-1962.

Weber, M. 2009. *From Max Weber: Essays in Sociology.* New York: Routledge.

World Resources Institute. 2012. Marine Jurisdictions: Coastal Length. Available at: http://web.archive.org/web/20120419075053/http:/earthtrends.wri.org/text/coastal-marine/variable-61.html. Accessed 03/11 2015.

Worldbank. 2014a. Worldwide Governance Indicators. Available at: http://info.worldbank.org/governance/wgi/index.aspx#home. Accessed 03/11 2015.

Worldbank. 2014b. GDP per capita. Available at: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD. Accessed 03/11 2015.

Worldbank. 2005a. Crop Production. Available at: http://data.worldbank.org/indicator/AG.PRD.CROP.XD. Accessed 03/11 2015.

Worldbank. 2005b. Livestock Production. Available at: http://data.worldbank.org/indicator/AG.PRD.LVSK.XD/countries. Accessed 03/11 2015.

Worldbank. 2000a. Fixed Broadband Subscribers. Available at: http://data.worldbank.org/indicator/IT.NET.BBND.P2. Accessed 03/11 2015.

Worldbank. 2000b. Passenger Cars. Available at: http://data.worldbank.org/indicator/IS.VEH.PCAR.P3. Accessed 03/11 2015.

Worldbank. 2000c. Military Expenditure, % of GDP. Available at: http://data.worldbank.org/indicator/MS.MIL.XPND.GD.ZS. Accessed 03/11 2015.

Worldbank. 2000d. Armed Forces Personnel. Available at: http://data.worldbank.org/indicator/MS.MIL.TOTL.P1. Accessed 03/11 2015.

Worldbank. 2000e. GINI Index, World Bank Estimate. Available at: http://data.worldbank.org/indicator/SI.POV.GINI. Accessed 03/11 2015.

Wright, S. 1921. Correlation and causation. *Journal of Agricultural Research* 20557-585.

CHAPTER 3: Paper 2 - Biochemical Methane Potential of High Solid Swine Manure under Thermophilic Anaerobic Digestion

Abstract

Concentrated swine farm operations produce sizeable amounts of manure, which are commonly treated using anaerobic lagoons which have been associated with a number of adverse environmental and health problems. The recent introduction of a separation system, known as a scraper, allows for the collection of manure without added water either as scraped solids (SS) and scraped liquids or as whole slurry (WS). A biochemical methane potential (BMP) test was conducted in order to determine the methane potential of these two substrates, at two different mesophilic temperatures of 25°C and 35°C. Average net methane production was found to be 279, 442, 297, 272 mL per gram of VS added for SS-25°C, WS-25°C, SS-35°C and WS-35°C, respectively. Two separate single-factor ANOVA tests determined there was no statistical significant difference among WS and SS, for both tested temperatures. While not significantly different, greater methane production from the WS-25°C treatment was attributed to acclimatization of this treatment. Additionally, high variability within treatments was attributed to heterogeneity in the collected manure samples. Recommendations for future efforts include acclimatization of inoculum to substrate, as well as grinding or blending of substrate.

1. Introduction

Energy demand is rapidly growing. World energy consumption is expected to grow 56% from 2010 and 2040, going from 552,000 quadrillion MJ to 865,100 quadrillion MJ (EIA, 2013). Similarly, global greenhouse gas (GHG) emissions have increased by up to 35% from 1990 to 2010 (EPA, 2014). The second greatest supplier sector, with up to 13% contribution in 2010, was the agriculture industry (EPA, 2014). In order to minimize global warming and climate change impacts GHG emissions must be reduced. These global challenges are to be faced not only with GHG mitigation, but also with implementation of new technologies that are able to address the problem at its source. In this context, biogas production from agricultural wastes and residues show great potential as part of the solution as it not only produces methane as a form of energy, but also collects GHG emissions that would otherwise be emitted into the atmosphere. The production of biogas through anaerobic digestion has proven to be effective in many European countries, such as Germany and Denmark (Weiland, 2010).

In the United States swine production has dramatically increased, adding over 5.9 billion kg to the total hog production between 1988 and 2015 (USDA, 1988, 2015). North Carolina is the second largest hog-producing state in the country (USDA, 2014), but, unlike Midwest producers, employs lagoon-sprayfield waste management systems, which have been associated with environmental concerns (Liang et al., 2002; Mallin, 2000; Schiffman et al., 2005; Schinasi et al., 2011; USDA, 2012) and lose potential resources in the form of methane, nitrogen as volatilized ammonia, and phosphorus in the bottom sludge of the lagoon. In this context, anaerobic digestion technology provides an alternative waste management solution that not only reduces emissions but also recovers methane and preserves nitrogen and phosphorus for subsequent recovery.

Different factors affecting the biogas production and methane yield of anaerobically digested swine manure that is used as the main substrate include animal's growth stage, feeding quantity and quality, and animal's health status. The most studied animal waste is cow manure (Gontupil, 2013; Raposo et al., 2011); swine manure has been studied to a smaller degree and most studies focus on co-digestion of swine manure and other carbon-rich products (Álvarez et al. , 2010; Cuetos et al., 2011; Fischer et al., 1983; Fujita et al., 1980).

Swine manure co-digestion has been scarcely researched in comparison to co-digestion of dairy and cattle manure. Cuetos et al. (2011) researched anaerobic co-digestion of swine manure, collected as whole slurry, with various energy crops (sunflower, maize and rapeseed waste) in 3 different proportions (25,50, and 75% volatile solids) to determine the optimal feedstock combination to maximize biogas. They concluded that co-digestion increased biogas production and that rapeseeds waste yielded the highest amount of biogas compared with the other crops.

Research done by K. Hansen et al. (1999) determined that methane production from swine manure collected as slurry can be maximized by introducing activated carbon or $FeCl_2$ to the biomass, as it counteracts ammonia inhibition. K. Hansen et al. (1999) determined increased hydraulic retention time (from 15 to 30 days) improved methane production yields. Lastly, Campos et al. (2008) studied the feasibility of anaerobic digestion of the solid portion of swine slurry. The solid-liquid separation process of swine slurry was conducted by adding polyacrylamide (PAM) as a flocculent to the manure. However, adding PAM may introduce a toxicity problem, as Campos et al. (2008) research suggests that the use of high PAM concentration (12 g/kg TS) inhibits the digestion process. For treatments under this threshold there was no statistically significant difference in methane production by swine slurry treated with PAM and the control group (solely swine slurry). The recent implementation of a new scraper system in North Carolina for swine waste removal has introduced opportunities to collect manure solids and liquids separately. This mechanical system allows for solid-liquid separation, reducing chances of chemical interference with the digestion process (such as PAM toxicity challenge on digestion). The scraper system allows the farmer to collect the waste as scraped slurry or as separated scraped solids and liquids. Thus, it enables the collection of different substrate compositions that may result in different opportunities for treatment and recovery of energy and nutrients. While the scraper system has been introduced in only a limited number of farms, if paired with appropriate technologies, such a system has the potential to generate new sources of revenue. Implementation of this scraper system at a larger scale is dependent upon the potential benefits provided by pairing different waste streams paired with appropriate technologies. A biochemical methane potential analysis was conducted in order to determine the difference in methane production potential between swine manure solids scraped without waste liquid and swine manure scraped from the barn as whole slurry. The objective of this research is to determine the potential of methane production per mass of volatile solids (VS) of swine manure collected in two different forms, scraped solids and whole slurry at two different temperatures, 25°C and 35°C.

2. Materials and Methods

2.1. Inoculum and Substrate Origin

Swine manure samples from two different Murphy-Brown, LLC farms were collected due to its difference in collection method. Murphy-Brown, LLC operates two different type of scrapers in their finishing hog barns. The scraper at Murphy Family Venture farm removes slurry manure twice per day. The Murphy Family Venture farm operates a system which takes scraped whole slurry into an equalization tank before directing it into the anaerobic digester. The digester is designed and operated at 25-27°C by Revolution Energy Solutions (RES). The scraper at the Holmes-Foster farm allows liquids to drain continuously to liquid storage; when the scraper operates twice per day, a cover diverts the collected solids to a separate collection tank. The Murphy Family Venture farm provided the whole slurry test material (total solids, 23.84 g/L) and the inoculum (21.07 g/L total solids); the Holmes-Foster farm provided the scraped solids test material (total solids, 206.9 g/L).

2.2. Biochemical Methane Potential (BMP) Assay

A series of batch experiments were designed to determine the methane potential of swine manure in two different forms: whole slurry (WS) and scraped solids (SS) at two different mesophilic temperatures (25°C and 35°C). The experiment followed a randomized block design with three treatment groups: WS, SS, and a blank group. Each treatment group consisted of four replicates, giving a total of 12 batch reactors as experimental units. To account for the volume of methane produced from the inoculum itself four blank replicates with inoculum were included. Figure 1 shows the schematic of the experimental set-up used to conduct the BMP assays.

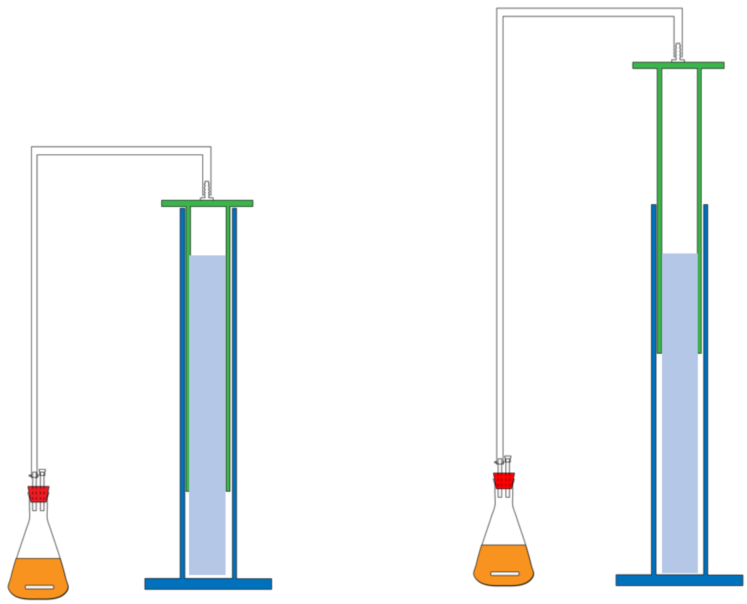

Figure 1. Schematic of the Biochemical Methane Potential experimental set-up.

As shown in Figure 1 the physical batch reactors were 500mL Erlenmeyer flasks, which were connected via plastic tubing to an inverted graduated cylinder. The top graduated cylinder rested inside a larger graduated cylinder filled with 900 mL of 1.0 M NaOH solution to absorb CO_2. Under this configuration, the two graduated cylinders acted as a gas meter via volume displacement.

All replicates were loaded at a substrate to inoculum ratio of 0.6 based on volatile solids (VS), with the volume of inoculum in each digester (150 mL) held constant, and a total working volume of 300 mL. The inoculum ratio fell within the range suggested by (Esposito et al., 2012) of 0.5-2.1 g VS substrate/g VS inoculum. Each batch reactor was purged with N_2 for 3min, to remove O_2 before it was sealed. Batch reactors were placed in a thermostatically-controlled water bath, where they were acclimated to the respective temperature. The contents of the reactor were continuously stirred at 270 rpm using magnetic bars. The methane produced was recorded three times a day until methane production ceased. Daily local pressure and room temperature were recorded at the time of measurement. The observed methane measurements were then adjusted to standard pressure (1atm) and temperature (25°C).

2.3. Analytical Methodology

The Environmental Analysis Laboratory, located in the North Carolina State University's Biological and Agricultural Engineering department, analyzed the manure samples. Analyses included total solids (TS), volatile solids (VS), and pH, which were determined following the American Public Health Association (APHA) standard methods and EPA approved methods. Analysis of total solids was completed using a gravimetric method, following standards methods 2540B (APHA, 2012; US EPA, 1983). Similarly, the volatile solids analysis was completed the ignition-gravimetric method, following methods 2540E. The pH of the samples was determined using a pH meter.

Biogas production was measured by fluid volume displacement; according to Drosg et al. (2013) introducing an alkaline solution, such as NaOH, in the gas collection vessel removes CO_2 and H_2S and allows direct measurement of the methane volume. Thus, a 1 M NaOH (pH of 13.40) solution was used to scrub the CO_2 from the biogas produced in the batch reactors. Thus, all collected gas was assumed to be methane.

2.4. Statistical Analysis

A single factor Analysis of Variance (ANOVA) was used to determine if there was a significant difference between the averages of the net accumulated methane production of the two different treatment groups (WS versus SS). The ANOVA procedure was performed using the SAS software version 9.4 (SAS Institute Inc., 2013). A value of p less than or equal to 0.05 was considered to indicate statistical significance.

3. Results and Discussion

3.1. Methane Production

In order to calculate total net methane produced for each replicate the average of the maximum values of methane produced by the blank replicates was subtracted from the maximum methane produced for each replicate for both treatments. These calculations were done for the two BMP assays at temperature 25°C and 35°C. Figure 2 shows the average net methane yield for each treatment group (SS-25°C, WS-25°C, SS-35°C, WS-35°C) per gram of VS added. Error bars represent standard error for the net methane yields for each substrate at respective temperatures.

Figure 2 shows very little variability within and between treatments conducted under 35°C, thus methane production was comparably the same for both WS and SS under 35°C. Under this temperature the average volume of methane produced was 297±25 mL/g VS added for scraped solids and 272±61 mL/g VS added for whole slurry. The average found on this BMP study falls within reported methane ranges on comparable studies. In a series of BMPs conducted by Labatut et al. (2011), under constant mesophilic temperature (35°C), he determined average methane production to be 243±60 mL/g VS added. In a similar setting Vedrenne et al. (2008) reported a range of 204-296 mL CH_4/g VS added, while Möller et al. (2004) reported comparable, yet slightly lower, results of average methane production of 148±41 mL/g VS added. A value of 241 mL CH_4/g VS added was reported El-Mashad & Zhang (2010) under similar mesophilic digestion of 35°C. Reported results from this study also compare well with results reported by Hoffmann et al. (2008) on a study with four CSTRs that were operated at three different hydraulic retention times and 35°C, with an average production of 241 mL CH_4/g VS added.

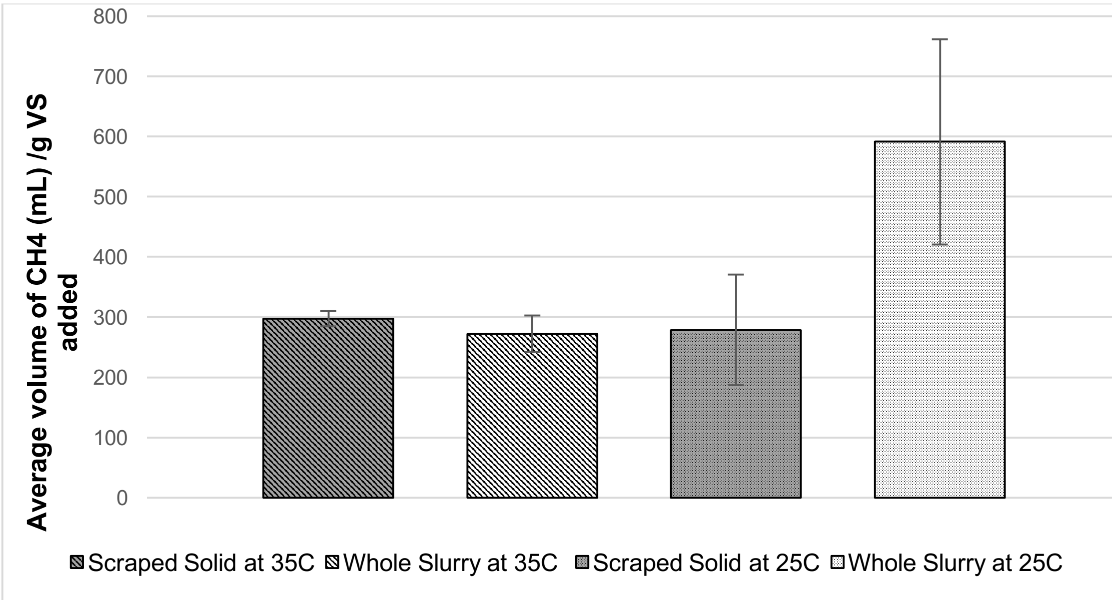

Figure 2. Observed net methane yield (mL) per gram of volatile solids added for each treatment when anaerobically digested at 25°C and 35°C. Error bars represent standard error for net methane yields for each substrate at respective temperatures

On the other hand Figure 2 shows great variability within treatment groups digested under 25°C. The large error bars under 25°C show the high variability within treatment group for both treatments. Whole slurry replicates showed the greatest variability among the two treatments. One replicate (WS3-25°C) under the whole slurry treatment showed to be exceptionally high, with 1.5 to 3.2 times higher than other three replicates within this treatment. Under 25°C the whole slurry replicates showed the greatest variability among the two treatments. The average net volume of methane produced under 25°C was 279±184 mL/g VS added for scraped solids and 591±341 mL/g VS added for whole slurry. The average methane production reported for SS-25°C is comparable to the overall average value reported by the IPCC (1997) of 240 mL CH_4/g VS added. The high methane production value reported for WS-25°C is likely due to the high variability within the treatment, section 3 discusses what likely caused such variability.

3.2. Statistical Results

Two separate single-factor ANOVA tests, for temperature 25°C and for 35°C, were conducted to determine if methane production was different for digesters with swine manure collected differently, as SS and WS. Replicates were classified into two groups: SS ($n=4$ for both temperatures of 25°C and 35°C) and WS ($n=4$ for both temperature of 25°C and 35°C, respectively) . There were no outliers, as assessed by boxplot; data was normally distributed for each group, as assessed by Shapiro-Wilk test ($p>0.5$); and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances ($p<0.469$ for 35°C and $p<0.157$ for 25°C).

For BMP performed under 35°C the methane production value was not statistically significantly different between the two different treatment groups, $F(1, 6) = 0.598$, $p=0.469$. Thus, there is enough statistical evidence, at the 0.05 significance level, to conclude that the mean difference of methane production among substrate treatments (SS versus WS) digested at temperature 35°C is not statistically different. Similarly, the ANOVA analysis for the BMP performed under 25°C, the methane production value was also found to be not significantly different between SS and WS, $F(1, 6) = 2.61$, $p=0.157$. Therefore, at the 0.05 significant level, there is enough evidence to conclude that the mean difference of methane production among treatments is not statistically different.

3.3. Methane Production Variability

While the average of methane production for the WS was about 2.1 times greater than production achieved using the scraped solids, high variability was observed within the WS treatment. Generally, this unusually high variability could be explained, in part, by the lack of homogeneity in the manure sample. While we assumed manure samples to be homogenous in nature, the collected manure samples often showed to have larger pieces of organic matter within the mixture. This issue was addressed by the researchers, in part, by introducing manure samples that had been well mixed into the batch reactors. However, there was no additional processing to break down larger pieces (such and grinding or blending) to obtain a fully homogeneous sample. As a result, one replicate—such as WS3-25°C —likely obtained a higher amount of organic matter than the other replicates, which in turn was reflected by high variability in total net methane production within treatment.

These findings are in accordance with Moody (2011), who determined that sample homogeneity had an important effect in the variability of BMP results. Sample homogeneity has been determined to play an important role in the methane production potential. According to Jeong (2010) as particle size decreases an increased surface area increases reactive sites for digestion, thus enhancing the digestion process. While lack of homogeneity may have played a role, explaining methane production variability for the BMP performed under 25°C, little variability was observed on the BMP assay performed under 35°C. Additionally, the goal was to determine the methane potential of SS and WS under realistic conditions without introducing any additional processing.

Furthermore, inoculum acclimation may have played an important role. When comparing methane production across temperatures 25°C and 35°C, variability in collected results were much more prevalent on the digestion performed at a 25°C temperature. In addition to the lack of homogeneity in samples attributing to the high variability observed, the inoculum performance—in particular at the lower temperature of 25°C—was likely to have had an advantage on the WS over the SS. Inoculum acclimation to temperature and substrate has shown to considerably increase digestion performance and reduce chances of inhibition (Chen et al., 2008; Gonçalves et al., 2011; Gonzalez-Fernandez & Garcıa-Encina, 2009; Jeong et al., 2010). The inoculum was collected from an established anaerobic digester digesting WS as main substrate, which was operating at 25°C. Thus, it is likely that the WS-25°C treatment had an advantage due to inoculum acclimatization. This would in part explain why the WS-25°C had the highest average methane production when compared to other treatments.

3.4. Design Implications

While the experimental BMPs showed no significant difference on methane production among swine manure collected as WS and SS, the substrate volume directed to an implemented digester is significantly different for these two collection methods. Data provided by Murphy-Brown, LLC allows us to compare the volumes of waste when collected as WS and SS. The following table shows the average daily volume of swine waste of a typical barn in NC (Holmes-Foster farm) with an operating scraper system installed. These averages were calculated from six data collection events over 6 months. Since there were a different number of pigs in the barn on collection days, these values are reported in terms of 1,000 finishing hogs.

Table 1. Means and standard deviations of waste volume data collected from a single barn (with an average of 1,000 finishing hogs) with an operating scraper system, in the Holmes-Foster farm operated by Murphy-Brown, LLC.

	Scraped Solids		**Whole Slurry**	
Temperature	35°C	25°C	35°C	25°C
Waste (L/1,000 hd/day)	1,200±333	1,200±333	6,230±1,308	6,230±1,308
VS content (kg/1,000 hd/day)	33±18	33±18	68±26	68±26
Potential CH_4 production (L/kg VS added)	10,098±5,229	9,486±4,912	18,405±7,021	39,991±15,256

As observed in Table 1, for anaerobic digestion purposes collecting waste in the form of WS represents up to 5.2 times more waste volume on average than when collecting the SS separately. Anaerobic digester up-front costs are largely dependent upon reactor size. An important barrier for anaerobic digestion implementation for many farm operators includes the high up-front capital investment (Nizami & Maclean, 2013; Penn State Extension, 2016). In a study conducted by Williams (2006) an anaerobic digestion system, designed for a feeder to finish hog farm operation with 12 houses containing 960 finishing hogs each, was evaluated; the Cost and Returns Analysis of Manure Management Systems report presented by Williams (2006) indicated that up to 63% of costs of the implementation of a mesophilic digester were associated to the steel tank reactor alone. This farm size is typical in North Carolina, and is comparable to the studied Holmes-Foster farm owned by Murphy-Brown, LLC.

As shown in Table 1, the WS volume shows a 419% increase in volume when compared to waste collected as SS. Meanwhile, there is a 106% difference between WS and SS for VS content. Higher VS content has been correlated to greater methane potential (Drosg et al., 2013; Lesteur et al., 2010; Moody et al., 2011; Pham et al., 2013). This can be observed in Table 1. Higher volume and VS content resulted in greater CH_4 potential; CH_4 potential for WS is 82.3% greater than SS under 35°C and 321% greater under 25°C.

While the highest methane production potential is observed under treatment WS-25°C due to higher waste volume and VS content, previously discussed limitations are important to consider. Methane potential production for WS is 1.67 times greater when compared to SS under mesophilic conditions of 35°C. On the other hand, under a 25°C, the WS methane production potential is up to 3.95 times greater than SS under same conditions. However, a smaller reactor digesting SS has the possibility of producing comparable volume of methane, in terms of VS content added, than a reactor digesting WS. The smaller reactor intended for SS digestion is likely to have significant lower costs than a reactor designed to digest WS waste volumes; this in turn would provide greater opportunities for adoption in the swine industry. In order to create a cost-effective and efficient waste management option the combination of waste volume and VS content needs to considered, as digester volume capacity is directly related to implementation costs.

References

Alfa, M. I., Adie, D. B., Igboro, S. B., Oranusi, U. S., Dahunsi, S. O., & Akali, D. M. (2014). Assessment of biofertilizer quality and health implications of anaerobic digestion effluent of cow dung and chicken droppings. *Renewable Energy*, *63*, 681–686.

http://doi.org/10.1016/j.renene.2013.09.049

Álvarez, J. A., Otero, L., & Lema, J. M. (2010). A methodology for optimising feed composition for anaerobic co-digestion of agro-industrial wastes. *Bioresource Technology*, *101*(4), 1153–1158. http://doi.org/10.1016/j.biortech.2009.09.061

Alvarez, J. a, Otero, L., Lema, J. M., & Omil, F. (2010). The effect and fate of antibiotics during the anaerobic digestion of pig manure. *Bioresource Technology*, *101*(22), 8581–6. http://doi.org/10.1016/j.biortech.2010.06.075

American Public Health Association. (2012). *Standard methods for the examination of water and wastewater.* (E. W. Rice, R. B. Baird, A. D. Eaton, & L. S. Clesceri, Eds.) (22nd ed.). Washington DC: American Public Health Association.

Amin, S. (1976). Unequal Development: An Essay on the Formation of Peripheral Capitalism. *Monthly Review Press.*

Appelbaum, R. P., & Robinson, W. I. (2005). *Critical globalization studies*. New York: Routledge.

Bagge, E., Sahlström, L., & Albihn, A. (2005). The effect of hygienic treatment on the microbial flora of biowaste at biogas plants. *Water Research*, *39*(20), 4879–86. http://doi.org/10.1016/j.watres.2005.03.016

Barker, J. C. (1996). *Lagoon Design and Management For Livestock Waste Treatment and Storage*. *NC State University Cooperative Extension* (Vol. 103). Retrieved from https://www.bae.ncsu.edu/extension/ext-publications/waste/animal/ebae-103-83-lagoon-design-barker.pdf

Battye, R., Battye, C., Overcash, C., & Fudge, S. (1994). *Development and Selection of Ammonia Emission Factors*. Research Triangle park. Durham, NC.

Boe, K., Kougias, P. G., Pacheco, F., O-Thong, S., & Angelidaki, I. (2012). Effect of substrates and intermediate compounds on foaming in manure digestion systems. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *66*(10), 2146–54.http://doi.org/10.2166/wst.2012.438

Boske, J., Wirth, B., Garlipp, F., Mumme, J., & Van den Weghe, H. (2015). Upflow anaerobic solid-state (UASS) digestion of horse manure: Thermophilic vs. mesophilic performance. *Bioresource Technology*, *175*, 8–16. http://doi.org/10.1016/j.biortech.2014.10.041

Brady, D., Kaya, Y., & Beckfield, J. (2007). Reassessing the effect of economic growth on well-being in less-developed countries, 1980-2003. *Studies in Comparative International Development*, *42*(1–2), 1–35. http://doi.org/10.1007/s12116-007-9003-7

Campos, E., Almirall, M., Mtnez-Almela, J., Palatsi, J., & Flotats, X. (2008). Feasibility study of the anaerobic digestion of dewatered pig slurry by means of polyacrylamide. *Bioresource Technology*, *99*(2), 387–95. http://doi.org/10.1016/j.biortech.2006.12.008

Carolan, M. (2012). *The Sociology of Food and Agriculture*. London, New York: Routledge.

Cavinato, C., Fatone, F., Bolzonella, D., & Pavan, P. (2010). Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy crops: Comparison of pilot and full scale experiences. *Bioresource Technology*, *101*(2), 545–550. http://doi.org/10.1016/j.biortech.2009.08.043

Chase-Dunn, C. (1989). *Global Formation: Structures of the Global Economy. American Sociological Review*. Cambridge, MA: Basil Blackwell.

Chase-Dunn, C. (2006). “Globalization: A World-Systems Perspective.” In C. Chase-Dunn & S. Babones (Eds.), *Global Social Change: Historical and Comparative Perspectives*. Baltimore: The Johns Hopkins University Press.

Chen, T. H., & Hashimoto, A. G. (1996). Effects of pH and substrate: Inoculum ratio on Batch Methane Fermentation. *Bioresource Technology*, *56*, 179–186.

Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource Technology*, *99*(10), 4044–64. http://doi.org/10.1016/j.biortech.2007.01.057

Cheng, J. (Ed.). (2010). *Biomass to Renewable Energy Processes*. CRC Press, Taylor & Francis Group.

Chynoweth, D. P., & Isaaccson, R. (1987). *Anaerobic Digestion of Biomass* (1st ed.). Elsevier Applied Science.

Comte, A. (1824). A general view of positivism. New York: Appleton.

Conway, G. (1998). *The doubly green revolution: food for all in the twenty-first century*. Ithaca: Comstock Pub. Associates.

Cooney, C. L., & Wise, D. L. (1975). Thermophilic Anaerobic Digestion of Solid Waste for Fuel Gas Production. *Biotechnology and Bioengineering*, *XVII*, 1119–1135.

Crouse, D. A., Barker, J. C., & Havlin, J. L. (n.d.). *Use of On-Farm Records for Modifying a Certified Animal Waste Management Plan*. Raleigh, NC. Retrieved from http://www.ncagr.gov/SWC/tech/documents/AppenxFarmRecordsAG-439-42.pdf

Cuetos, M. J., Fernández, C., Gómez, X., & Morán, A. (2011). Anaerobic co-digestion of swine manure with energy crop residues. *Biotechnology and Bioprocess Engineering*, *16*(5), 1044–1052. http://doi.org/10.1007/s12257-011-0117-4

De Baere, L. (2001). Anaerobic digestion of solid waste : state-of-the-art. *Waster Science and Technology*, 283–290.

De Janvry, A. (1981). *The agrarian question and reformism in Latin America*. Baltimore: The Johns Hopkins University Press.

De Vries, J. W., Vinken, T. M. W. J., Hamelin, L., & De Boer, I. J. M. (2012). Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy--a life cycle perspective. *Bioresource Technology*, *125*, 239–48. http://doi.org/10.1016/j.biortech.2012.08.124

Dincer, I. (2010). *Global Warming*. (I. Dincer, A. Hepbasli, A. Midilli, & T. H. Karakoc, Eds.). Boston, MA: Springer US. http://doi.org/10.1007/978-1-4419-1017-2

Drosg, B., Braun, R., Bochmann, G., & Al Saedi, T. (2013). *Analysis and characterisation of biogas feedstocks*. *Woodhead Publishing Series in Energy*. http://doi.org/http://dx.doi.org/10.1533/9780857097415.1.52

Durkheim, E. (1984). *The division of labor in society*. New York: Free Press.

El-Mashad, H. M., & Zhang, R. (2010). Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology*, *101*(11), 4021–4028. http://doi.org/10.1016/j.biortech.2010.01.027

Energy Information Administration. (2013). *EIA projects world energy consumption will* *increase 56% by 2040*. United States. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=12251

Environmental Protection Agency. (2014). *Global Greenhouse Gas Emissions*. Retrieved from http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

Esposito, G., Frunzo, L., Liotta, F., Panico, A., & Pirozzi, F. (2012). Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates. *The Open Environmental Engineering Journal*, *5*(1), 1–8. http://doi.org/10.2174/1874829501205010001

Fan, S., & Rosegrant, M. (2008). Investing in agriculture to overcome the world food crisis and reduce poverty and hunger. *IFPRI Policy Brief*, *3*(June), 4. Retrieved from http://sanrem.cals.vt.edu/1323/investing in agriculture.pdf

Ferrer, P., Cambra-López, M., Cerisuelo, A., Peñaranda, D. S., & Moset, V. (2014). The use of agricultural substrates to improve methane yield in anaerobic co-digestion with pig slurry: effect of substrate type and inclusion level. *Waste Management (New York, N.Y.)*, *34*(1), 196–203. http://doi.org/10.1016/j.wasman.2013.10.010

Field, J. A., Caldwell, J. S., Jeyanayagam, S., Reneau, R. B., Kroontje, W., & Collins, E. R. (1984). Fertilizer Recovery from Anaerobic Digesters. *Transactions of the ASAE*, 56–60.

Firebaugh, G. (1996). Does Foreign Capital Harm Poor Nations? New Estimates Based on Dixon and Boswell's Measures of Capital Penetration. *American Journal of Sociology*, *102*(2), 563. http://doi.org/10.1086/230957

Fischer, J. R., Ianotti, E. L., & Fulhage, C. D. (1983). Production of methane gas from combinations of wheat straw and swine manure. *Transactions of the ASAE*, *26*(2), 546–548.

Food and Agricuture Organization. (1998). *The FAO Definition of Sustainable Development and the Code of Conduct for Responsible Fisheries: an analysis of the related principles, criteria and indicators*. Rome.

Food and Agricuture Organization. (2004). *The State of Food and Agriculture 2003–2004*. Rome.

Frank, A. G. (1966). The Development of Underdevelopment. *Monthly Review Press.*, *18*, 17–31.

Fujita, M., Scharer, J. M., & Moo-Young, M. (1980). Effect of corn stover addition on the anaerobic digestion of swine manure. *Agricultural Wastes*, *2*(3), 177–184. http://doi.org/10.1016/0141-4607(80)90014-1

Galli, R. E. (1981). *The Political economy of rural development : peasants, international capital, and the state : case studies in Columbia, Mexico, Tanzania, and Bangladesh*. Albany: State University of New York Press.

Goberna, M., Schoen, M. A., Sperl, D., Wett, B., & Insam, H. (2010). Mesophilic and thermophilic co-fermentation of cattle excreta and olive mill wastes in pilot anaerobic digesters. *Biomass and Bioenergy*, *34*(3), 340–346. http://doi.org/10.1016/j.biombioe.2009.11.005

Gonçalves, M. R., Costa, J. C., Marques, I. P., & Alves, M. M. (2011). Inoculum acclimation to oleate promotes the conversion of olive mill wastewater to methane. *Energy*, *36*(4), 2138–2141. http://doi.org/10.1016/j.energy.2010.04.042

Gontupil, J. (2013). *Anaerobic Co-digestion of Swine Manure and Agricultural Residues for Biogas Production*. North Carolina State University.

Gonzalez-Fernandez, C., & Garcıa-Encina, P. A. (2009). Impact of substrate to inoculum ratio in anaerobic digestion of swine slurry. *Biomass and Bioenergy*, *33*, 1065–1069. http://doi.org/10.1016/j.biombioe.2009.03.008

Guendouz, J., Buffière, P., Cacho, J., Carrère, M., & Delgenes, J.-P. (2008). High-solids anaerobic digestion: comparison of three pilot scales. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *58*(9), 1757–63. http://doi.org/10.2166/wst.2008.521

Gunaseelan, V. N. (1994). Effect of Inoculum/Substrate ratio a pretreatments on methane yield from Parthenium. *Biomass and Bioenergy*, *8*(1), 39–44.

Hansen, K., Angelidaki, I., & Ahring, B. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8). Retrieved from http://www.sciencedirect.com/science/article/pii/S0043135498004102

Hansen, K. H., Angelidaki, I., & Ahring, B. K. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8), 1805–1810. http://doi.org/10.1016/S0043-1354(98)00410-2

Hashimoto, A. G. (1983). Thermophilic and Mesophilic Anaerobic Fermentation of Swine Manure. *Agricultural Wastes*, *6*, 175–191.

Hashimoto, A. G. (1984). Methane from Swine Manure : Effect of Temperature and Influent Substrate Concentration on Kinetic Parameter (K). *Agricultural Wastes*, *9*, 299–308.

Hashimoto, A. G. (1989). Effect of Inoculum [Substrate Ratio on Methane Yield and Production Rate from Straw Experiment design. *Biological Wastes*, *28*, 247–255.

Hindle, T. (2008). *The Economist Guide to Management Ideas and Gurus*. (The Economist, Ed.). Bloomberg Press.

Hoffmann, R. A., Garcia, M. L., Veskivar, M., Karim, K., Al-Dahhan, M. H., & Angenent, L. T. (2008). Effect of shear on performance and microbial ecology of continuously stirred anaerobic digesters treating animal manure. *Biotechnology and Bioengineering*, *100*(1), 38–48. http://doi.org/10.1002/bit.21730

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*, *100*(22), 5478–84. http://doi.org/10.1016/j.biortech.2008.12.046

Huang, J. J. H., & Shih, J. C. H. (1981). The potential of biological methane generation from chicken manure. *Biotechnology and Bioengineering*, *23*(10), 2307–2314. http://doi.org/10.1002/bit.260231013

Inkeles, A. (1975). Becoming Modern: Individual Change in Six Developing Countries. *American Anthropological Association Stable*, *3*(2), 323–342.

International Energy Statistics. (2012).

IPCC. (1997). *Guidelines for National Greenhouse Gas Inventories: Reference Manual*.

Jenkins, J. C., & Scanlan, S. J. (2001). Food Security in Less Developed Countries, 1970 To 1990. *American Sociological Review*, *66*(5), 718–744. http://doi.org/10.2307/3088955

Jenkins, J. C., Scanlan, S. J., & Peterson, L. (2007). Military Famine, Human Rights, and Child Hunger: A Cross-National Analysis, 1990-2000. *The Journal of Conflict Resolution*, *51*(6), 823-827-833-847. Retrieved from http://search.proquest.com/docview/224558559?accountid=10673

Jeong, E., Kim, H. W., Nam, J. Y., & Shin, H. S. (2010). Enhancement of bioenergy production and effluent quality by integrating optimized acidification with submerged anaerobic membrane bioreactor. *Bioresource Technology*, *101*(1 SUPPL.), S7–S12. http://doi.org/10.1016/j.biortech.2009.04.064

Kaparaju, P., & Rintala, J. (2011). Mitigation of greenhouse gas emissions by adopting anaerobic digestion technology on dairy, sow and pig farms in Finland. *Renewable Energy*, *36*(1), 31–41. http://doi.org/10.1016/j.renene.2010.05.016

Khalid, A., Arshad, M., Anjum, M., Mahmood, T., & Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste Management (New York, N.Y.)*, *31*(8), 1737–44. http://doi.org/10.1016/j.wasman.2011.03.021

Kick, E. L., McKinney, L. a., & Thompson, G. H. (2011). Intensity of food deprivation: The integrative impacts of the world system, modernization, conflict, militarization and the environment. *International Journal of Comparative Sociology*, *52*(6), 478–502. http://doi.org/10.1177/0020715211428181

Kim, J. K., Oh, B. R., Chun, Y. N., & Kim, S. W. (2006). Effects of temperature and hydraulic retention time on anaerobic digestion of food waste. *Journal of Bioscience and Bioengineering*, *102*(4), 328–32. http://doi.org/10.1263/jbb.102.328

Krugman, P. (1999). *The return of depression economics*. New York: W. W. Norton.

Labatut, R. A., Angenent, L. T., & Scott, N. R. (2011). Biochemical methane potential and biodegradability of complex organic substrates. *Bioresource Technology*, *102*(3), 2255–2264. http://doi.org/10.1016/j.biortech.2010.10.035

Lehtomaki, A., Huttunen, S., & Rintala, J. A. (2007). Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio. *Resources, Conservation and Recycling*, *51*(3), 591–609.

http://doi.org/10.1016/j.resconrec.2006.11.004

Lesteur, M., Bellon-Maurel, V., Gonzalez, C., Latrille, E., Roger, J. M., Junqua, G., & Steyer, J. P. (2010). Alternative methods for determining anaerobic biodegradability: A review. *Process Biochemistry*, *45*(4), 431–440. http://doi.org/10.1016/j.procbio.2009.11.018

Li, Y., Park, S. Y., & Zhu, J. (2011). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews*, *15*(1), 821–826. http://doi.org/10.1016/j.rser.2010.07.042

Li, Y., Zhang, R., Liu, X., Chen, C., Xiao, X., Feng, L., … Liu, G. (2013). Evaluating Methane Production from Anaerobic Mono- and Co-digestion of Kitchen Waste, Corn Stover, and Chicken Manure. *Energy & Fuels*, *27*(4), 2085–2091. http://doi.org/10.1021/ef400117f

Liang, Z. S., Westerman, P. W., & Arogo, J. (2002). Modeling Ammonia Emission from Swine Anaerobic Lagoons, *45*(3), 787–798.

Lipton, M. (1975). Urban bias and food policy in poor countries. *Food Policy*, *1*(1), 41–52. http://doi.org/10.1016/0306-9192(75)90007-X

Lipton, M. (1977). *Why poor people stay poor : urban bias in world development*. Cambridge: Harvard University Press.

Luning, L., van Zundert, E. H. M., & Brinkmann, A. J. F. (2003). Comparison of dry and wet digestion for solid waste. *Water Science and Technology*, *48*(4), 15–20.

Machethe, C. (2004). Agriculture and poverty in South Africa: Can agriculture reduce poverty. In *Overcoming Underdevelopment Conference* (pp. 1–14). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.1551&rep=rep1&type=pdf

Mallin, M. (2000). Impacts of Industrial Animal Production on Rivers and Estuaries. *American Scientist*, *88*(1), 26. http://doi.org/10.1511/2000.1.26

Massé, D. I., Croteau, F., & Masse, L. (2007, November). The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors. *Bioresource Technology*. http://doi.org/10.1016/j.biortech.2006.07.040

Massé, D. I., Talbot, G., & Gilbert, Y. (2011). On farm biogas production: A method to reduce

GHG emissions and develop more sustainable livestock operations. *Animal Feed Science and Technology*, *166–167*, 436–445. http://doi.org/10.1016/j.anifeedsci.2011.04.075

Mata-Alvarez, J., & Llabres, S. M. (2000). Anaerobic digestion of organic solid wastes . An overview of research achievements and perspectives. *Bioresource Technology*, *74*, 3–16.

McCarty, P. L. (1964). Anaerobic Waste Treatment Fundamentals I: Chemistry and Microbiology. *Public Works*, 107–112.

McMichael, P. (2009). A food regime genealogy. *Journal of Peasant Studies*, *36*(1), 139–169. http://doi.org/10.1080/03066150902820354

Mebratu, D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, *18*(6), 493–520. http://doi.org/10.1016/S0195-9255(98)00019-5

Messner, H., & Amberger, A. (1987). Composition, nitrification and fertilizing effect of anaerobically fermented slurry. *Agricultural Waste Management and Environmental Protection*, 125–130.

Moller, H. B., Sommer, S. G., & Ahring, B. K. (2004). Methane productivity of manure, straw and solid fractions of manure. *Biomass and Bioenergy*, *26*(5), 485–495. http://doi.org/10.1016/j.biombioe.2003.08.008

Moody, L. B., Burns, R. T., Bishop, G., Sell, S. T., & Spajic, R. (2011). Using Biochemical Methane Potential Assays to Aid in Co-substrate Selection for Co- digestion. *Transactions of the ASABE*, *27*(3), 433–439.

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, *1*(1), 1–27. http://doi.org/10.14448/jes.01.0002

Moritzer, E. (2008). Curse or blessing? *Kunststoffe International*, *98*(3), 38–39.

Moset, V., Bertolini, E., Cerisuelo, A., Cambra, M., Olmos, A., & Cambra-López, M. (2014). Start-up strategies for thermophilic anaerobic digestion of pig manure. *Energy*, *74*, 389–395. http://doi.org/10.1016/j.energy.2014.07.003

Ni, J.-Q., Heber, A. J., Sutton, A. L., Kelly, D. T., Patterson, J. a, & Kim, S.-T. (2010). Effect of swine manure dilution on ammonia, hydrogen sulfide, carbon dioxide, and sulfur dioxide releases. *The Science of the Total Environment*, *408*(23), 5917–23. http://doi.org/10.1016/j.scitotenv.2010.08.031

Nizami, A.-S., & Maclean, H. L. (2013). Anaerobic Digesters : challenges and perspectives. In N. Korres, P. O'Kiely, J. Benzie, & J. West (Eds.), *Bioenergy Production by Anaerobic Digestion Using Agricultural Biomass and Organic Waste*. Routledge, Taylor and Francis. http://doi.org/10.13140/2.1.1405.0241

Nwabanne, J. T., Onukwuli, O. D., & Ifeakandu, C. M. (2009). Biokinetics of Anaerobic Digestion of Municipal Waste. *International Journal Environmental Resources*, *3*(4), 511–517.

Panichnumsin, P., Nopharatana, A., Ahring, B., & Pawinee, C. (2010). Production of methane by co-digestion of cassava pulp with various concentrations of pig manure. *Biomass and Bioenergy*, *34*(8), 1117–1124.

Parsons, T. (1964). *Social structure and personality.* New York: Free Press of Glencoe.

Penn State Extension. (n.d.). *Agronomy Guide* (AGRS-026). State College, PA. Retrieved from http://extension.psu.edu/agronomy-guide/cm/sec2/sec28

Penn State Extension. (2016). *Anaerobic Digestion: Biogas Production and Odor Reduction from Manure*. State College, PA. Retrieved from http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/projects/g-77

Pham, C. H., Triolo, J. M., Cu, T. T. T., Pedersen, L., & Sommer, S. G. (2013). Validation and recommendation of methods to measure biogas production potential of animal manure. *Asian-Australasian Journal of Animal Sciences*, *26*(6). http://doi.org/10.5713/ajas.2012.12623

Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308.

Protection, U. S. E., & Agstar, A. (2011). Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures, (March).

Raposo, F., Banks, C. J., Siegert, I., Heaven, S., & Borja, R. (2006). Influence of inoculum to substrate ratio on the biochemical methane potential of maize in batch tests, *41*, 1444–

1450. http://doi.org/10.1016/j.procbio.2006.01.012

Raposo, F., De la Rubia, M. a., Fernández-Cegrí, V., & Borja, R. (2012). Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews*, *16*(1), 861–877. http://doi.org/10.1016/j.rser.2011.09.008

Raposo, F., Fernandez-Cegri, V., de la Rubia, M. A., Borja, R., Beline, F., Cavinato, C., … de Wilde, V. (2011). Biochemical methane potential (BMP) of solid organic substrates: Evaluation of anaerobic biodegradability using data from an international interlaboratory study. *Journal of Chemical Technology and Biotechnology*, *86*(8), 1088–1098. http://doi.org/10.1002/jctb.2622

Rapport, J., Zhang, R., Jenkins, B., & Williams, R. (2008). *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste*. *IWMB-2008-0011*. California. Retrieved from http://www.calrecycle.ca.gov/publications/Detail.aspx?PublicationID=1275

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384. http://doi.org/10.1016/j.ecolecon.2003.10.017

Rodriguez Andara, A., & Lomas Esteban, J. M. (1999). Kinetic study of the anaerobic digestion of the solid fraction of piggery slurries. *Biomass and Bioenergy*, *17*, 435–443.

Rostow, W. (1960). *The stages of economic growth: a non-communist manifesto*. New york: Cambridge University Press.

Safferman, S. I., Kirk, D. M., Faivor, L. L., & Wu-haan, W. (2012). Anaerobic Digestion Processes. In *Bioremediation and Sustainability* (pp. 103–136). http://doi.org/10.1002/9781118371220.ch3

Sahlstr, L. (2003). A review of survival of pathogenic bacteria in organic waste used in biogas plants, *87*, 161–166.

Santos, V. E., Naval, L., Guardiola, E., & Lo, B. (1999). Kinetic model for anaerobic digestion of livestock manure, *25*, 55–60.

SAS Institute Inc. (2013). Cary, NC.

Scanlan, S. J. (2001). Guns, butter, and development: Security and military famine extensions of the modernization versus dependency debate. *Journal of Political & Military Sociology*, *29*(2), 331–355.

Schiffman, S. S., Studwell, C. E., Landerman, L. R., Berman, K., & Sundy, J. S. (2005). Symptomatic Effects of Exposure to Diluted Air Sampled from a Swine Confinement Atmosphere on Healthy Human Subjects. *Environmental Health Perspectives*, *113*(5), 567–76. http://doi.org/10.1289/ehp.6814

Schinasi, L., Horton, R. A., Guidry, V., Wing, S., Marshall, S., & Morland, K. (2011). Air Pollution, Lung Functions, and Physical Symptoms in Communities near concentrated Swine Feeding Operations.pdf. *Epidemiology*, *22*(2), 208–15.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford: Clarendon Press.

Skorov, G. (1973). The green revolution and social progress. *World Development*, *1*(11), 13–21.

Stromberg, S., Nistor, M., & Liu, J. (2014). Towards eliminating systematic errors caused by the experimental conditions in Biochemical Methane Potential (BMP) tests. *Waste Management*, *34*(11), 1939–1948. http://doi.org/10.1016/j.wasman.2014.07.018

Sunkel, O. (1969). National development policy and external dependence in Latin America. *Journal of Development Studies*. http://doi.org/10.1080/00220386908421311

Suryawanshi, P. C., Chaudhari, A. B., & Kothari, R. M. (2010). Mesophilic anaerobic digestion : first option for waste treatment in tropical regions, *30*(March), 259–282. http://doi.org/10.3109/07388551.2010.487047

Switzenbaum, M. S. (1995). Obtacles in the Implementation of Anaerobic Treatment Technology. *Bioresource Technology*, *53*(95), 255–262.

Tafdrup, S. (1995). Viable Energy Production And Waste Recycling From Anaerobic Digestion Of Manure And Other Biomass Materials. *Biomass and Bioenergy*, *9*(95), 303–314.

Thompson, G. H. (2012). *A Macro-Comparative Analysis of Global Hunger across Developing Countries: The Integrative Impacts of Global and National Development, Gendered Inequalities, Conflict and Militarization, the Global Food System, and Environment. PhD Proposal*. North Carolina State University. http://doi.org/10.1017/CBO9781107415324.004

Toman, M. a. (1992). The difficulty in defining sustainability. *Rources*. http://doi.org/10.4324/9781936331642

Tomei, M. C., Braguglia, C. M., Cento, G., & Mininni, G. (2009). Modeling of Anaerobic Digestion of Sludge. *Critical Reviews in Environmental Science and Technology*, *39*(12), 1003–1051. http://doi.org/10.1080/10643380801977818

U.S. Environmental Protection Agency. (n.d.). Overview of Anaerobic Digestion and Digesters. Retrieved from http://www.epa.gov/region2/webinars/pdfs/3-24-10_1.pdf

United States Department of Agriculture. (2007). *Hog and Pig Farming*.

United States Department of Agriculture. (2014). *Biogas Opportunities Roadmap*. Retrieved from http://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf

United States Department of Agriculture, N. R. C. S. (2012). Agricultural Wastes and Water, Air , and Animal Resources. In *Agricultural Waste Management Field Handbook* (p. Part 651). USDA.

United States Department of Agriculture, & Department of Commerce. (1982). Census of Agriculture. http://doi.org/10.5962/bhl.title.18473

United States Department of Agriculture, & National Agricultural Statistics Service. Census of Agriculture, Pub. L. No. AC-12-A-51 (2012). United States.

United States Environmental Protection Agency. (1983). *Methods for Chemical Analysis of Water and Wastes*. Cincinatti, OH.

US Department of Agriculture National Agricultural Service. (1988). Census of Agriculture. Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Department of Agriculture National Agricultural Service. (2014). Census of Agriculture.

US Department of Agriculture National Agricultural Service. (2015). Census of Agriculture. Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Environmental Protection Agency. (1999). *Feedlots Point Source Category Study*. Retrieved from http://water.epa.gov/scitech/wastetech/guide/cafo/feedlots_index.cfm

Vanderholm, D., & Melvin, S. (2009). *Scraper Systems for Removing Manure From Swine Facilities*.

Vanotti, M., Szogi, A., Pilar Bernal, M., & Martinez, J. (2009). Livestock waste treatment systems of the future: a challenge to environmental quality, food safety, and sustainability. OECD Workshop. *Bioresource Technology*, *100*(22), 5371–3. http://doi.org/10.1016/j.biortech.2009.07.038

Vedrenne, F., Beline, F., Dabert, P., & Bernet, N. (2008). The effect of incubation conditions on the laboratory measurement of the methane producing capacity of livestock wastes. *Bioresource Technology*, *99*(1), 146–155.http://doi.org/10.1016/j.biortech.2006.11.043

Vos, R. O. (2007). Defining Sustainability: a conceptual orientation. *Journal of Chemical Technology & Biotechnology*, *82*(May), 334–339. http://doi.org/10.1002/jctb

Wallerstein, I. (1974). *The Modern World System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century.* New York, NY: Academic Press.

Weiland, P. (2010). Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology*, *85*(4), 849–60. http://doi.org/10.1007/s00253-009-2246-7

Williams, C. M. (2006). *Cost and Returns Analysis of Manure Management Systems Evaluated in 2004 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers*. Raleigh, NC.

Wing, S., & Wolf, S. (2000). Intensive livestock operations, health, and quality of life among eastern North Carolina residents. *Environmental Health Perspectives*, *108*(3), 233–238. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1637983/

World Bank. (2007). *World Development Report: Agriculture for Development.* Washington DC.

World Commision of Environment and Development. (1987). *Our Common Future*. *United*

Nations. New York. http://doi.org/10.1080/07488008808408783

Yadvika, Santosh, Sreekrishnan, T. R., Kohli, S., & Rana, V. (2004). Enhancement of biogas production from solid substrates using different techniques--a review. *Bioresource Technology*, *95*(1), 1–10. http://doi.org/10.1016/j.biortech.2004.02.010

Yargeau, V. (2014). *Biomethane Potential (BMP) Assay Protocol*.

Yenigün, O., & Demirel, B. (2013). Ammonia inhibition in anaerobic digestion: A review. *Process Biochemistry*, *48*(5–6), 901–911. http://doi.org/10.1016/j.procbio.2013.04.012

CHAPTER 4: Additional Considerations for Future Research

In conducting biochemical methane potential (BMP) assays the research team faced a number of challenges and unexpected results documented here. A BMP test was conducted at thermophilic temperature (63°C) following the same methods as those described for BMPSs under mesophilic conditions discussed in Chapter 3; observed results and analysis will be reported in Section I. Section II will address equipment challenges and unexpected system design operation experienced on all BMPs iterations conducted. Additionally, this chapter addresses more generally some considerations and limitations in regards to the BMPs procedure in Section III.

1. Biochemical Methane Production Assays at Thermophilic Temperature

1.1. Substrate and Inoculum Origin

Swine manure samples from two different Murphy Brown farm locations were collected due to its difference in collection method. Samples for whole slurry (23.84 g/L total solids) were obtained from manure flushed out of the barns from the Murphy Family Venture farm. A second farm, Holmes-Foster farm provided the scraped solids (206.9 g/L total solids) samples using a scraper system installed to collect and remove waste from the hog farms. The scraper at the Holmes-Foster farm allows liquids to drain continuously to liquid storage; when the scraper operates twice per day, a cover diverts the collected solids to a separate collection tank. The inoculum was obtained from the swine unit at the Lake Wheeler Road Flied Laboratory (LWRFL) of North Carolina State University. Sludge collected from the swine lagoon on the LWRFL was used as inoculum only for BMP assays operated at 63°C (32.09 g/L total solids).

A series of batch experiments were designed to determine the methane potential of anaerobic digestion of swine manure in two different forms: whole slurry (WS) and scraped solids (SS). Set-up was conducted at 63°C. The experiment followed a randomized block design with three treatment groups: WS, SS, and a blank group. Each treatment group consisted of four replicates, giving a total of 12 batch reactors as experimental units. To account for the volume of methane produced from the inoculum itself four blank replicates with solely inoculum were included.

The physical batch reactors were 500mL Erlenmeyer flasks. All replicates followed a volatile solids (VS) to inoculum ratio of 0.6, with the volume of inoculum in each digester (150 mL) held constant. The inoculum ratio fell within the range of 0.5-2.1 g VS substrate/g VS inoculum reported in literature (Esposito et al., 2012). Each batch reactor was purged with N_2 for 3min to remove O_2 before it was sealed. Batch reactors were placed in a thermostatic water bath where they were acclimated to respective temperature. The contents of the reactor were continuously stirred at 270 rpm using magnetic bars. The methane produced was measured three times a day, using a volume displacement gas meter, until methane production ceased. A 1 M NaOH (pH of 13.40) solution was used to scrub the CO_2 from the biogas produced in the batch reactors. Thus, all collected gas was assumed to be methane. Daily local pressure and room temperature were also recorded when the gas volume was measured. The observed methane measurements were then standardized to standard pressure (1 atm) and temperature (25°C) using the ideal gas law equation.

1.2. Analytical Methods

The Environmental Analysis Laboratory, located in the North Carolina State University's Biological and Agricultural Engineering department, analyzed all of the manure samples. Analyses included total solids (TS), volatile solids (VS), pH, TKN, NH_3N, NO_3N, TP, COD, and TOC were determined following the American Public Health Association (APHA) standard methods and EPA approved methods (APHA, 2012; US EPA, 1983). Table 1 lists the method and system used for each parameter measured in samples.

Table 1. Methods and systems used to determine various sample parameters

Parameter	Method	System
% Total Solids	Gravimetric method (Standard Methods 2540B)	N/A
% Volatile Solids	Ignition-gravimetric method (Standard Methods 2540E)	N/A
pH	pH meter	N/A
TKN	Acid digestion-salicylate/nitroprusside color-automated analysis (Standard Methods 4500-Norg B)	Bran & Luebbe Digital Autoanalyzer III system
NH_3N	Salicylate/nitroprusside color-automated analysis (Standard Methods 4500-NH3 G)	Bran & Luebbe Digital Autoanalyzer III system
NO_3N	Cadmium reduction-sulfanilamide/N-1 naphthylethylenediamine color-automated analysis (Standard Methods 4500-NO3-E)	Bran & Luebbe Digital Autoanalyzer III system
TP	Acid digestion-molybdate/antimony/ascorbic acid color-automated analysis (Standard Method 4500-P F)	Bran & Luebbe Digital Autoanalyzer III system
COD	Potassium dichromate/sulfuric acid digestion-colorimetric analysis (EPA approved method)	N/A
TOC	TOC analyzer (Standard Methods 5310 B)	Teledyne Tekmar Apollo 9000 combustion

1.3. Statistical Analysis

A single factor Analysis of Variance (ANOVA) was used to determine if there was a significant difference between the averages of net accumulated methane production of the two different treatment groups (WS versus SS), for temperatures 63°C, 35°C and 25°C. The ANOVA procedures were performed using the SAS software version 9.4 (SAS Institute Inc., 2013). An alpha value of 0.05 was considered to indicate statistical significance.

1.4. Methane Production

In order to calculate total net methane produced for each replicate the average of the maximum values of methane produced by the blank replicates was subtracted from the maximum methane produced for each replicate for both treatments. Cumulative methane volume produced by anaerobic digestion at 63°C, for a period of 6 days, can be observed in Figure 1.

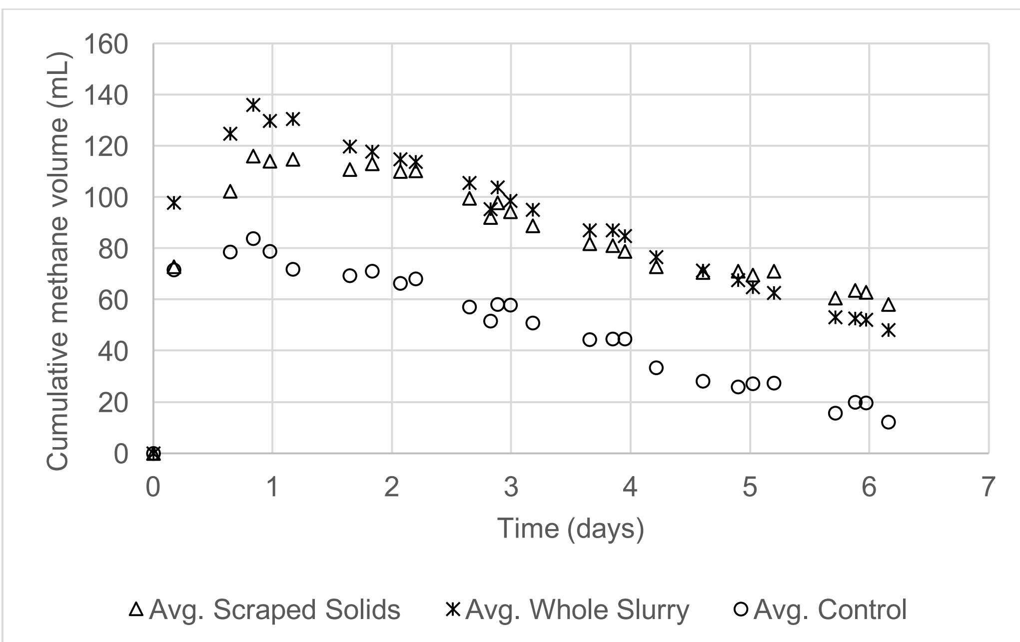

Figure 1. Average cumulative methane production for each treatment under 63°C

Figure 1 shows the methane production for each replicate during digestion time at a thermophilic temperature of 63°C. All replicates showed a small volume of methane production within the first hours. However, after day one the net methane production gradually started to go down for all replicates.

Theoretically, the design of the gas collection system should retain any produced volume of methane throughout time, showing a stable volume once the maximum volume has been reached. Therefore, it was expected that when gas production ceased, no change in volume would have been observed. However, contrary to expectations, the volume was not maintained after day one but steadily declined. As observed in Figure 1, the net volume of methane slowly came down back to zero after 6 days and the gas collection system was assumed to have leaks. Thus, after day 6 the experimental set-up was dismantled in order to investigate and repair any leaks.

Figure 2 shows the average net methane yield for each treatment group per gram of VS added. Error bars represent standard error for the net methane yields for each substrate at 63°C. As it can be observed in Figure 2, variation within treatment was comparable between the SS and WS treatments. Average net methane volume produced by the SS was slightly lower, at 53 mL per gram of VS added when compared to the net methane volume produced by the WS, at 86 mL per gram of VS added.

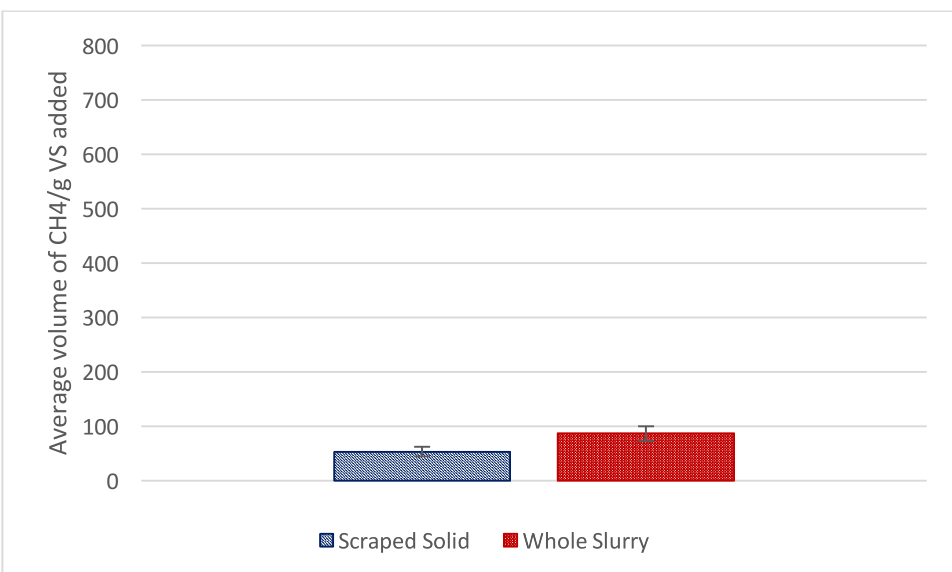

Figure 2. Observed net average methane yield (mL)per gram of volatile solids added for the SS and WS treatment when anaerobically digested at 63°C. Error bars represent standard error for net methane yields for each substrate.

1.4.1. Statistical Results

A one-way ANOVA was conducted to determine if the methane production was different for groups with swine manure collected in different ways (WS and SS). Replicates were classified into two groups: whole slurry (n=4), and scraped solids (n=4). There were no outliers, as assessed by boxplot; data was normally distributed for each treatment group, as assessed by Shapiro-Wilk test ($p<0.05$); and there was homogeneity of variances, as assessed by Levine's test of variance ($p=0.654$). Data is presented as mean ± standard deviation. At a 0.05 significance level the mean net methane production was not statistically significantly different between swine manure collected in different forms (WS and SS), $F(1, 6) = 4.287$, $p=0.084$. Mean methane production was found to be 86.25 ± 27.32 and 52.75 ± 17.35 mL CH_4/g VS added for WS and SS, respectively.

However, recorded methane volume production under this conditions are considerably low when compared to similar experiments. The IPCC (1997) reported an overall average methane production of 240 mL/g VS added, which is considerably higher than values reported here. Böske et al. (2015) found that thermophilic digestion of horse manure yielded a methane production range of 124.8-154.8 mL/g VS added. While the substrate on Böske et al. (2015) experiments is somewhat different in nature, results obtained under the BMPs at 63°C are significantly less. In terms of the digester performance, Figure 1 shows limited to no success on this experimental run. Digester failure is likely due to high temperature, as it is likely that the inoculum unsuccessfully acclimated to 63°C. While the researcher increased temperature gradually over a 24-hour span, microorganisms are likely to have been shocked and suffered under the high temperature. Inoculum was obtained from the lagoon sludge of the swine unit at the LWRFL of North Carolina State University, which is likely to be in a 20-25°C environment.

In order to address some of the challenges observed on the experiment set up at 63°C the research team ran the same BMP assay experiment at a lower temperature of 35°C and 25°C, which are discussed in Chapter 3.

2. Negative Pressure in Batch Reactors

Negative pressure was observed in many of the gas meters used for the BMP experiments done under mesophilic conditions. While we initially assumed leaks to be the issue at hand, during the mesophilic BMPs we determined that a negative pressure was a consistent phenomenon that occurred towards the end of the digestion cycle.

Figure 3 shows the average standardized cumulative methane volume (mL) of the three treatments: scraped solids, whole slurry, and blank (control) when digested under 35°C over a 12 day period.

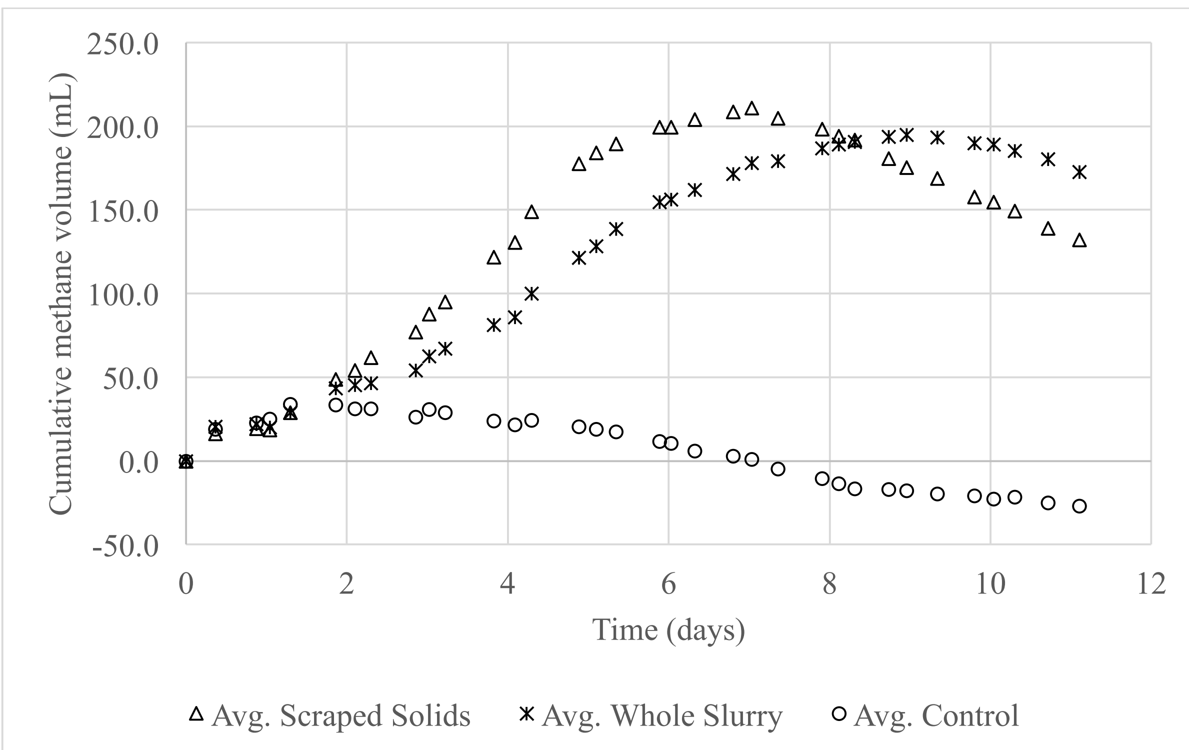

Figure 3. Average of cumulative methane production (mL) for 12 replicates over time for the three different treatments (SS, WS, Inoculum/Control), under 35°C.

The highest cumulative methane volume was produced by the whole slurry digesters. The maximum gas volume recorded was on day 8, day 10 and day 3 for the scraped solids, whole slurry and the blank (control) treatment, respectively.

However, our experiment showed unexpected results after day 3 for the inoculum replicates, after day 8 for the scraped solids replicates, and after day 10 for the whole slurry replicate. Contrary to our expectations, we observed a continuous decrease in the methane gas levels for all treatments. While we initially assumed this was due to leaks in the equipment (first BMP iteration where experiment was performed under thermophilic conditions), under mesophilic conditions of 35°C the control group indicated negative readings after day 8. For instance, at time zero (beginning of day 1) the control #3 had a reading of 155 mL (reading taken using the top graduated cylinder, which shows increments of 5mL). However, on day 12 control #3 had an unstandardized measurement of 110mL, which when standardized to account for both ambient temperature and pressure, corresponds to going from 160.6mL on day 1 to -38.4mL on day 12.

While it is uncertain what factors specifically resulted in producing a vacuum effect, it is possible that the microbial population of the collected inoculum may have interfered with gas production. The microbial population of the inoculum may have not properly adapted to the whole slurry and scraped solids environment, as the site of collection for the inoculum is atypical. The LWRFL swine lagoon is primarily a research facility for the North Carolina State University, and it is significantly over-designed for the number of hogs that are on the farm at any given time. Therefore, the volatile solids loading rate is significantly lower than those of typical lagoons. Additionally, there is a solids settling basin in order to remove heavy solids before flushing into the lagoon, reducing the volatile solids content even further. Thus, the flush water in the lagoon is significantly diluted compared to regular operations. While this might be a factor, it is uncertain how this might contribute to the vacuum effect observed in the blank replicates.

Additionally, the operating temperature of the swine lagoon located at LWRFL is considerably under 35°C, with a temperature around 20-25°C. Although an acclimation process was performed on the inoculum by slowly increasing the temperature by 2.5 degrees every 36 to 48 hours until the final temperature was reached, we believe the microorganisms may have suffered temperature shock and terminated biogas production earlier than expected. This would in part explain why the replicates under the control treatment stopped methane production after day 5, which is the day the temperature finally reached 35°C. However, this hypothesis does not explain the prolonged methane production for the SS and WS replicates until day 8 and 10, respectively.

In order to assess the likelihood of this hypothesis, new inoculum was collected for a third BMP experimental set-up in a mesophilic environment of 25°C. Concerning factors, such as the source of the inoculum and its operating temperature, were considered for the BMP experimental set up by reducing operating temperature from 35°C to 25°C and sourcing inoculum from an established digester (covered in Chapter 3). The inoculum was collected from the Murphy Brown Family Venture farm, which operates a system that takes scraped whole slurry into an equalization tank before directing it into an anaerobic digester. These digesters are designed and operated at 25-27°C by Revolution Energy Solutions (RES). The inoculum used for the BMP assay operated at 25°C was collected from waste biomass of one of the reactors. This allowed us to determine if inoculum source and temperature played as significant a role as we had previously hypothesized. Figure 6 shows the average standardized cumulative methane volume (mL) of the three treatments: scraped solids, whole slurry, and blank (control) when digested at 25°C over a 20 day period.

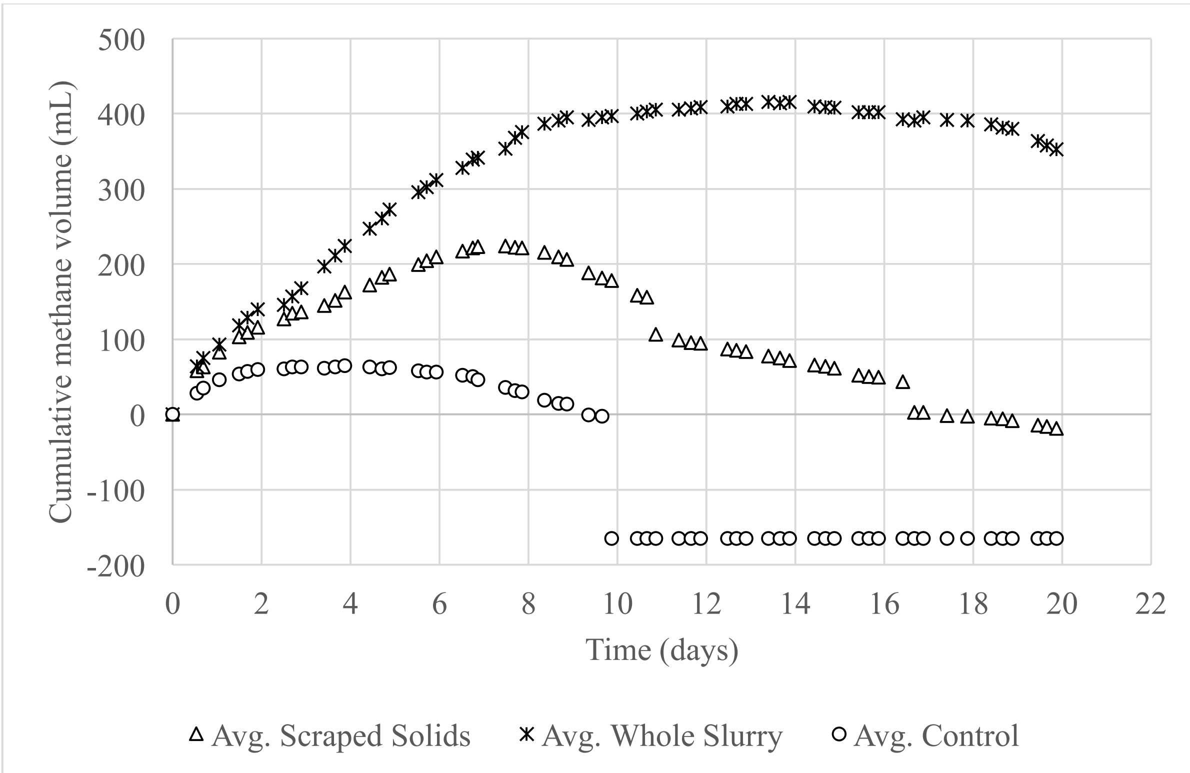

Figure 4. Average of cumulative methane production (mL) for 12 replicates over time for the three different treatments (SS, WS, Inoculum/Control), under 25°C.

Similarly, as observed in Figure 3, Figure 4 shows a negative gas production volume after day 10 and day 15 for the blank (control) and scraped solids, respectively. Thus, it is unlikely that the inoculum temperature used previously, from LWRFL, played a significant role in gas production and its respective collection system. However, it is likely that inoculum acclimatization played some degree in gas production. As observed in Figure 6 the WS treatment decreased the least, when compared to other treatments, as time elapsed. As expected the inoculum adaptation, which was sourced from a digester processing WS as its substrate, proved to be the highest under the WS treatment. While a slight decrease in volume was observed for the WS treatment after day 18, the methane volume produced by WS remained mostly constant for 20 days. However, it is likely that if the digestion period had been extended longer we would have observed a similar behavior exhibited by other treatments.

3. Biochemical Methane Potential (BMP) Assay Limitations

Future research should focus on understanding the various factors that must be considered when conducting a biochemical methane potential (BMP) assay, as no official protocol is available, and the ones available through literature vary from one another. In a BMP assay protocol developed by McGill University in collaboration with Anaergia (Yargeau, 2014) a 0.2 gram of VS waste for every gram VS inoculum ratio, with a temperature of 35°C controlled by a water bath, is stipulated as part of the protocol. In another publication, conducted by Esposito et al. (2012) a substrate to inoculum ratio ranging between 0.5 and 2.3 grams of VS of waste over grams of VS of inoculum is suggested. However, neither of these protocols mention the need for standardizing recorded volumes to account for local atmospheric pressure and ambient temperature. This is a critical missing component, as Stromberg et al. (2014) determined ambient pressure and temperature, in the calculated methane potential, had the largest effect. Since there is no official standard protocol for BMP assays, often the most common conditions mentioned in literature are applied. However, this presents a problem as there are some variables that might be not considered by the researcher while some variables might not be specified in published existing literature. It is often the case that the BMP assay results for the same waste yield different results between research labs (Stromberg et al., 2014). In a study conducted by Raposo et al. (2011), many research groups participated in different worldwide locations conducting anaerobic digestion of the same substrates (starch, cellulose, and gelatin). Raposo et al. (2011) found that the inoculum's nature and experimental factors involved in BMP assays were close to insignificant for the same waste, while the methane production rates differed significantly according to the approach taken for BMP test. In a similar study done by Stromberg et al. (2014), where they evaluated the effects of performing BMP tests under extreme environmental conditions that represent different geographical locations, he ascertained that local temperature and pressure are critical to accurate calculation of standard gas volumes from observed values. Other factors to consider, which often vary or are ignored by researchers, include water vapor and headspace gas composition, gas solubility, particle size, origin of inoculum, inoculum-to-substrate ratio in terms of volatile solids, and mixing rate (Boe et al., 2012; K. Hansen et al., 1999; Raposo et al., 2011; Raposo et al., 2006; Stromberg et al., 2014).

4. Conclusions and Future Research

A BMP experimental set up was conducted on swine manure collected in two forms, SS (240.0 g/L total solids) and WS (23.84 g/L total solids), at a thermophilic temperature (63°C) to determine the biochemical methane potential of the two substrates. Lagoon sludge was used as inoculum. On average, methane production for SS was 53 mL/ g VS added and for WS was 86mL/g VS added under 63°C.

A one-way ANOVA tests determined that, at a 0.05 significance level, the mean difference of methane production among the two substrate treatments (SS and WS) was not significantly different. Variability within and between treatments was very low. The inoculum sample was collected from a lagoon (sludge) which is naturally assumed to operate at 20-25°C. Thus, microorganisms were likely to be shocked and methanogens destroyed under the higher temperature, resulting in biogas underproduction.

Successful adoption of anaerobic digestion technology in hog farms in NC highly depends on the benefits and return of investment time the anaerobic digestion technology provides. How the manure is collected, and if there is a scraper on-site, how the scraper is operated to collect WS or SS is an important consideration. Scraper operation greatly affects the digester design, which in turn affects implementation costs. Operating the scraper to collect SS reduces waste volume by up to a factor of 5 times, while only reducing the VS content by a factor of 1.9 and producing comparable yields of methane gas. While there was no statistical significant difference among treatments, future efforts must include sample grinding or blending—to maximize reactive sites for digestion and minimize variability in VS added—as well as inoculum acclimatization to all treatments to enhance methane production and reduce inhibition. Additionally, the development and publication of BMP test protocols are critical to generate meaningful and comparable research.

References

Alfa, M. I., Adie, D. B., Igboro, S. B., Oranusi, U. S., Dahunsi, S. O., & Akali, D. M. (2014). Assessment of biofertilizer quality and health implications of anaerobic digestion effluent of cow dung and chicken droppings. *Renewable Energy*, *63*, 681–686. http://doi.org/10.1016/j.renene.2013.09.049

Álvarez, J. A., Otero, L., & Lema, J. M. (2010). A methodology for optimising feed composition for anaerobic co-digestion of agro-industrial wastes. *Bioresource Technology*, *101*(4), 1153–1158. http://doi.org/10.1016/j.biortech.2009.09.061

Alvarez, J. a, Otero, L., Lema, J. M., & Omil, F. (2010). The effect and fate of antibiotics during the anaerobic digestion of pig manure. *Bioresource Technology*, *101*(22), 8581–6. http://doi.org/10.1016/j.biortech.2010.06.075

American Public Health Association. (2012). *Standard methods for the examination of water and wastewater.* (E. W. Rice, R. B. Baird, A. D. Eaton, & L. S. Clesceri, Eds.) (22nd ed.). Washington DC: American Public Health Association.

Amin, S. (1976). Unequal Development: An Essay on the Formation of Peripheral Capitalism. *Monthly Review Press.*

Appelbaum, R. P., & Robinson, W. I. (2005). *Critical globalization studies*. New York: Routledge.

Bagge, E., Sahlström, L., & Albihn, A. (2005). The effect of hygienic treatment on the microbial flora of biowaste at biogas plants. *Water Research*, *39*(20), 4879–86. http://doi.org/10.1016/j.watres.2005.03.016

Barker, J. C. (1996). *Lagoon Design and Management For Livestock Waste Treatment and Storage*. *NC State University Cooperative Extension* (Vol. 103). Retrieved from https://www.bae.ncsu.edu/extension/ext-publications/waste/animal/ebae-103-83-lagoon-design-barker.pdf

Battye, R., Battye, C., Overcash, C., & Fudge, S. (1994). *Development and Selection of Ammonia Emission Factors*. Research Triangle park. Durham, NC.

Boe, K., Kougias, P. G., Pacheco, F., O-Thong, S., & Angelidaki, I. (2012). Effect of substrates and intermediate compounds on foaming in manure digestion systems. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *66*(10), 2146–54. http://doi.org/10.2166/wst.2012.438

Boske, J., Wirth, B., Garlipp, F., Mumme, J., & Van den Weghe, H. (2015). Upflow anaerobic solid-state (UASS) digestion of horse manure: Thermophilic vs. mesophilic performance. *Bioresource Technology*, *175*, 8–16. http://doi.org/10.1016/j.biortech.2014.10.041

Brady, D., Kaya, Y., & Beckfield, J. (2007). Reassessing the effect of economic growth on well-being in less-developed countries, 1980-2003. *Studies in Comparative International Development*, *42*(1–2), 1–35. http://doi.org/10.1007/s12116-007-9003-7

Campos, E., Almirall, M., Mtnez-Almela, J., Palatsi, J., & Flotats, X. (2008). Feasibility study of the anaerobic digestion of dewatered pig slurry by means of polyacrylamide. *Bioresource Technology*, *99*(2), 387–95. http://doi.org/10.1016/j.biortech.2006.12.008

Carolan, M. (2012). *The Sociology of Food and Agriculture*. London, New York: Routledge.

Cavinato, C., Fatone, F., Bolzonella, D., & Pavan, P. (2010). Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy crops: Comparison of pilot and full scale experiences. *Bioresource Technology*, *101*(2), 545–550. http://doi.org/10.1016/j.biortech.2009.08.043

Chase-Dunn, C. (1989). *Global Formation: Structures of the Global Economy. American Sociological Review*. Cambridge, MA: Basil Blackwell.

Chase-Dunn, C. (2006). “Globalization: A World-Systems Perspective.” In C. Chase-Dunn & S. Babones (Eds.), *Global Social Change: Historical and Comparative Perspectives*. Baltimore: The Johns Hopkins University Press.

Chen, T. H., & Hashimoto, A. G. (1996). Effects of pH and substrate: Inoculum ratio on Batch Methane Fermentation. *Bioresource Technology*, *56*, 179–186.

Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource Technology*, *99*(10), 4044–64. http://doi.org/10.1016/j.biortech.2007.01.057

Cheng, J. (Ed.). (2010). *Biomass to Renewable Energy Processes*. CRC Press, Taylor &

Francis Group.

Chynoweth, D. P., & Isaaccson, R. (1987). *Anaerobic Digestion of Biomass* (1st ed.). Elsevier Applied Science.

Comte, A. (1824). A general view of positivism. New York: Appleton.

Conway, G. (1998). *The doubly green revolution: food for all in the twenty-first century*. Ithaca: Comstock Pub. Associates.

Cooney, C. L., & Wise, D. L. (1975). Thermophilic Anaerobic Digestion of Solid Waste for Fuel Gas Production. *Biotechnology and Bioengineering*, *XVII*, 1119–1135.

Crouse, D. A., Barker, J. C., & Havlin, J. L. (n.d.). *Use of On-Farm Records for Modifying a Certified Animal Waste Management Plan*. Raleigh, NC. Retrieved from http://www.ncagr.gov/SWC/tech/documents/AppenxFarmRecordsAG-439-42.pdf

Cuetos, M. J., Fernández, C., Gómez, X., & Morán, A. (2011). Anaerobic co-digestion of swine manure with energy crop residues. *Biotechnology and Bioprocess Engineering*, *16*(5), 1044–1052. http://doi.org/10.1007/s12257-011-0117-4

De Baere, L. (2001). Anaerobic digestion of solid waste : state-of-the-art. *Waster Science and Technology*, 283–290.

De Janvry, A. (1981). *The agrarian question and reformism in Latin America*. Baltimore: The Johns Hopkins University Press.

De Vries, J. W., Vinken, T. M. W. J., Hamelin, L., & De Boer, I. J. M. (2012). Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy--a life cycle perspective. *Bioresource Technology*, *125*, 239–48. http://doi.org/10.1016/j.biortech.2012.08.124

Dincer, I. (2010). *Global Warming*. (I. Dincer, A. Hepbasli, A. Midilli, & T. H. Karakoc, Eds.). Boston, MA: Springer US. http://doi.org/10.1007/978-1-4419-1017-2

Drosg, B., Braun, R., Bochmann, G., & Al Saedi, T. (2013). *Analysis and characterisation of biogas feedstocks*. *Woodhead Publishing Series in Energy*. http://doi.org/http://dx.doi.org/10.1533/9780857097415.1.52

Durkheim, E. (1984). *The division of labor in society*. New York: Free Press.

El-Mashad, H. M., & Zhang, R. (2010). Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology*, *101*(11), 4021–4028. http://doi.org/10.1016/j.biortech.2010.01.027

Energy Information Administration. (2013). *EIA projects world energy consumption will increase 56% by 2040*. United States. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=12251

Environmental Protection Agency. (2014). *Global Greenhouse Gas Emissions*. Retrieved from http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

Esposito, G., Frunzo, L., Liotta, F., Panico, A., & Pirozzi, F. (2012). Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates. *The Open Environmental Engineering Journal*, *5*(1), 1–8. http://doi.org/10.2174/1874829501205010001

Fan, S., & Rosegrant, M. (2008). Investing in agriculture to overcome the world food crisis and reduce poverty and hunger. *IFPRI Policy Brief*, *3*(June), 4. Retrieved from http://sanrem.cals.vt.edu/1323/investing in agriculture.pdf

Ferrer, P., Cambra-López, M., Cerisuelo, A., Peñaranda, D. S., & Moset, V. (2014). The use of agricultural substrates to improve methane yield in anaerobic co-digestion with pig slurry: effect of substrate type and inclusion level. *Waste Management (New York, N.Y.)*, *34*(1), 196–203. http://doi.org/10.1016/j.wasman.2013.10.010

Field, J. A., Caldwell, J. S., Jeyanayagam, S., Reneau, R. B., Kroontje, W., & Collins, E. R. (1984). Fertilizer Recovery from Anaerobic Digesters. *Transactions of the ASAE*, 56–60.

Firebaugh, G. (1996). Does Foreign Capital Harm Poor Nations? New Estimates Based on Dixon and Boswell's Measures of Capital Penetration. *American Journal of Sociology*, *102*(2), 563.http://doi.org/10.1086/230957

Fischer, J. R., Ianotti, E. L., & Fulhage, C. D. (1983). Production of methane gas from combinations of wheat straw and swine manure. *Transactions of the ASAE*, *26*(2), 546–548.

Food and Agricuture Organization. (1998). *The FAO Definition of Sustainable Development* *and the Code of Conduct for Responsible Fisheries: an analysis of the related principles, criteria and indicators*. Rome.

Food and Agricuture Organization. (2004). *The State of Food and Agriculture 2003–2004*. Rome.

Frank, A. G. (1966). The Development of Underdevelopment. *Monthly Review Press.*, *18*, 17–31.

Fujita, M., Scharer, J. M., & Moo-Young, M. (1980). Effect of corn stover addition on the anaerobic digestion of swine manure. *Agricultural Wastes*, *2*(3), 177–184. http://doi.org/10.1016/0141-4607(80)90014-1

Galli, R. E. (1981). *The Political economy of rural development : peasants, international capital, and the state : case studies in Columbia, Mexico, Tanzania, and Bangladesh*. Albany: State University of New York Press.

Goberna, M., Schoen, M. A., Sperl, D., Wett, B., & Insam, H. (2010). Mesophilic and thermophilic co-fermentation of cattle excreta and olive mill wastes in pilot anaerobic digesters. *Biomass and Bioenergy*, *34*(3), 340–346. http://doi.org/10.1016/j.biombioe.2009.11.005

Gonçalves, M. R., Costa, J. C., Marques, I. P., & Alves, M. M. (2011). Inoculum acclimation to oleate promotes the conversion of olive mill wastewater to methane. *Energy*, *36*(4), 2138–2141. http://doi.org/10.1016/j.energy.2010.04.042

Gontupil, J. (2013). *Anaerobic Co-digestion of Swine Manure and Agricultural Residues for Biogas Production*. North Carolina State University.

Gonzalez-Fernandez, C., & Garcıa-Encina, P. A. (2009). Impact of substrate to inoculum ratio in anaerobic digestion of swine slurry. *Biomass and Bioenergy*, *33*, 1065–1069. http://doi.org/10.1016/j.biombioe.2009.03.008

Guendouz, J., Buffière, P., Cacho, J., Carrère, M., & Delgenes, J.-P. (2008). High-solids anaerobic digestion: comparison of three pilot scales. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *58*(9), 1757–63. http://doi.org/10.2166/wst.2008.521

Gunaseelan, V. N. (1994). Effect of Inoculum/Substrate ratio a pretreatments on methane yield from Parthenium. *Biomass and Bioenergy*, *8*(1), 39–44.

Hansen, K., Angelidaki, I., & Ahring, B. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8). Retrieved from http://www.sciencedirect.com/science/article/pii/S0043135498004102

Hansen, K. H., Angelidaki, I., & Ahring, B. K. (1999). Improving thermophilic anaerobic digestion of swine manure. *Water Research*, *33*(8), 1805–1810. http://doi.org/10.1016/S0043-1354(98)00410-2

Hashimoto, A. G. (1983). Thermophilic and Mesophilic Anaerobic Fermentation of Swine Manure. *Agricultural Wastes*, *6*, 175–191.

Hashimoto, A. G. (1984). Methane from Swine Manure : Effect of Temperature and Influent Substrate Concentration on Kinetic Parameter (K). *Agricultural Wastes*, *9*, 299–308.

Hashimoto, A. G. (1989). Effect of Inoculum [Substrate Ratio on Methane Yield and Production Rate from Straw Experiment design. *Biological Wastes*, *28*, 247–255.

Hindle, T. (2008). *The Economist Guide to Management Ideas and Gurus*. (The Economist, Ed.). Bloomberg Press.

Hoffmann, R. A., Garcia, M. L., Veskivar, M., Karim, K., Al-Dahhan, M. H., & Angenent, L. T. (2008). Effect of shear on performance and microbial ecology of continuously stirred anaerobic digesters treating animal manure. *Biotechnology and Bioengineering*, *100*(1), 38–48. http://doi.org/10.1002/bit.21730

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*, *100*(22), 5478–84. http://doi.org/10.1016/j.biortech.2008.12.046

Huang, J. J. H., & Shih, J. C. H. (1981). The potential of biological methane generation from chicken manure. *Biotechnology and Bioengineering*, *23*(10), 2307–2314. http://doi.org/10.1002/bit.260231013

Inkeles, A. (1975). Becoming Modern: Individual Change in Six Developing Countries. *American Anthropological Association Stable*, *3*(2), 323–342.

International Energy Statistics. (2012).

IPCC. (1997). *Guidelines for National Greenhouse Gas Inventories: Reference Manual*.

Jenkins, J. C., & Scanlan, S. J. (2001). Food Security in Less Developed Countries, 1970 To 1990. *American Sociological Review*, *66*(5), 718–744.http://doi.org/10.2307/3088955

Jenkins, J. C., Scanlan, S. J., & Peterson, L. (2007). Military Famine, Human Rights, and Child Hunger: A Cross-National Analysis, 1990-2000. *The Journal of Conflict Resolution*, *51*(6), 823-827-833-847. Retrieved from http://search.proquest.com/docview/224558559?accountid=10673

Jeong, E., Kim, H. W., Nam, J. Y., & Shin, H. S. (2010). Enhancement of bioenergy production and effluent quality by integrating optimized acidification with submerged anaerobic membrane bioreactor. *Bioresource Technology*, *101*(1 SUPPL.), S7–S12. http://doi.org/10.1016/j.biortech.2009.04.064

Kaparaju, P., & Rintala, J. (2011). Mitigation of greenhouse gas emissions by adopting anaerobic digestion technology on dairy, sow and pig farms in Finland. *Renewable Energy*, *36*(1), 31–41. http://doi.org/10.1016/j.renene.2010.05.016

Khalid, A., Arshad, M., Anjum, M., Mahmood, T., & Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste Management (New York, N.Y.)*, *31*(8), 1737–44. http://doi.org/10.1016/j.wasman.2011.03.021

Kick, E. L., McKinney, L. a., & Thompson, G. H. (2011). Intensity of food deprivation: The integrative impacts of the world system, modernization, conflict, militarization and the environment. *International Journal of Comparative Sociology*, *52*(6), 478–502. http://doi.org/10.1177/0020715211428181

Kim, J. K., Oh, B. R., Chun, Y. N., & Kim, S. W. (2006). Effects of temperature and hydraulic retention time on anaerobic digestion of food waste. *Journal of Bioscience and Bioengineering*, *102*(4), 328–32. http://doi.org/10.1263/jbb.102.328

Krugman, P. (1999). *The return of depression economics*. New York: W. W. Norton.

Labatut, R. A., Angenent, L. T., & Scott, N. R. (2011). Biochemical methane potential and biodegradability of complex organic substrates. *Bioresource Technology*, *102*(3), 2255–

2264. http://doi.org/10.1016/j.biortech.2010.10.035

Lehtomaki, A., Huttunen, S., & Rintala, J. A. (2007). Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio. *Resources, Conservation and Recycling*, *51*(3), 591–609. http://doi.org/10.1016/j.resconrec.2006.11.004

Lesteur, M., Bellon-Maurel, V., Gonzalez, C., Latrille, E., Roger, J. M., Junqua, G., & Steyer, J. P. (2010). Alternative methods for determining anaerobic biodegradability: A review. *Process Biochemistry*, *45*(4), 431–440. http://doi.org/10.1016/j.procbio.2009.11.018

Li, Y., Park, S. Y., & Zhu, J. (2011). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews*, *15*(1), 821–826. http://doi.org/10.1016/j.rser.2010.07.042

Li, Y., Zhang, R., Liu, X., Chen, C., Xiao, X., Feng, L., … Liu, G. (2013). Evaluating Methane Production from Anaerobic Mono- and Co-digestion of Kitchen Waste, Corn Stover, and Chicken Manure. *Energy & Fuels*, *27*(4), 2085–2091. http://doi.org/10.1021/ef400117f

Liang, Z. S., Westerman, P. W., & Arogo, J. (2002). Modeling Ammonia Emission from Swine Anaerobic Lagoons, *45*(3), 787–798.

Lipton, M. (1975). Urban bias and food policy in poor countries. *Food Policy*, *1*(1), 41–52. http://doi.org/10.1016/0306-9192(75)90007-X

Lipton, M. (1977). *Why poor people stay poor : urban bias in world development*. Cambridge: Harvard University Press.

Luning, L., van Zundert, E. H. M., & Brinkmann, A. J. F. (2003). Comparison of dry and wet digestion for solid waste. *Water Science and Technology*, *48*(4), 15–20.

Machethe, C. (2004). Agriculture and poverty in South Africa: Can agriculture reduce poverty. In *Overcoming Underdevelopment Conference* (pp. 1–14). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.1551&rep=rep1&type=pdf

Mallin, M. (2000). Impacts of Industrial Animal Production on Rivers and Estuaries. *American Scientist*, *88*(1), 26. http://doi.org/10.1511/2000.1.26

Massé, D. I., Croteau, F., & Masse, L. (2007, November). The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors. *Bioresource Technology*. http://doi.org/10.1016/j.biortech.2006.07.040

Massé, D. I., Talbot, G., & Gilbert, Y. (2011). On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations. *Animal Feed Science and Technology*, *166–167*, 436–445. http://doi.org/10.1016/j.anifeedsci.2011.04.075

Mata-Alvarez, J., & Llabres, S. M. (2000). Anaerobic digestion of organic solid wastes . An overview of research achievements and perspectives. *Bioresource Technology*, *74*, 3–16.

McCarty, P. L. (1964). Anaerobic Waste Treatment Fundamentals I: Chemistry and Microbiology. *Public Works*, 107–112.

McMichael, P. (2009). A food regime genealogy. *Journal of Peasant Studies*, *36*(1), 139–169. http://doi.org/10.1080/03066150902820354

Mebratu, D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, *18*(6), 493–520. http://doi.org/10.1016/S0195-9255(98)00019-5

Messner, H., & Amberger, A. (1987). Composition, nitrification and fertilizing effect of anaerobically fermented slurry. *Agricultural Waste Management and Environmental Protection*, 125–130.

Moller, H. B., Sommer, S. G., & Ahring, B. K. (2004). Methane productivity of manure, straw and solid fractions of manure. *Biomass and Bioenergy*, *26*(5), 485–495. http://doi.org/10.1016/j.biombioe.2003.08.008

Moody, L. B., Burns, R. T., Bishop, G., Sell, S. T., & Spajic, R. (2011). Using Biochemical Methane Potential Assays to Aid in Co-substrate Selection for Co- digestion. *Transactions of the ASABE*, *27*(3), 433–439.

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, *1*(1), 1–27. http://doi.org/10.14448/jes.01.0002

Moritzer, E. (2008). Curse or blessing? *Kunststoffe International*, *98*(3), 38–39.

Moset, V., Bertolini, E., Cerisuelo, A., Cambra, M., Olmos, A., & Cambra-López, M. (2014).

Start-up strategies for thermophilic anaerobic digestion of pig manure. *Energy*, *74*, 389–395. http://doi.org/10.1016/j.energy.2014.07.003

Ni, J.-Q., Heber, A. J., Sutton, A. L., Kelly, D. T., Patterson, J. a, & Kim, S.-T. (2010). Effect of swine manure dilution on ammonia, hydrogen sulfide, carbon dioxide, and sulfur dioxide releases. *The Science of the Total Environment*, *408*(23), 5917–23. http://doi.org/10.1016/j.scitotenv.2010.08.031

Nizami, A.-S., & Maclean, H. L. (2013). Anaerobic Digesters : challenges and perspectives. In N. Korres, P. O'Kiely, J. Benzie, & J. West (Eds.), *Bioenergy Production by Anaerobic Digestion Using Agricultural Biomass and Organic Waste*. Routledge, Taylor and Francis. http://doi.org/10.13140/2.1.1405.0241

Nwabanne, J. T., Onukwuli, O. D., & Ifeakandu, C. M. (2009). Biokinetics of Anaerobic Digestion of Municipal Waste. *International Journal Environmental Resources*, *3*(4), 511–517.

Panichnumsin, P., Nopharatana, A., Ahring, B., & Pawinee, C. (2010). Production of methane by co-digestion of cassava pulp with various concentrations of pig manure. *Biomass and Bioenergy*, *34*(8), 1117–1124.

Parsons, T. (1964). *Social structure and personality.* New York: Free Press of Glencoe.

Penn State Extension. (n.d.). *Agronomy Guide* (AGRS-026). State College, PA. Retrieved from http://extension.psu.edu/agronomy-guide/cm/sec2/sec28

Penn State Extension. (2016). *Anaerobic Digestion: Biogas Production and Odor Reduction from Manure*. State College, PA. Retrieved from http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/projects/g-77

Pham, C. H., Triolo, J. M., Cu, T. T. T., Pedersen, L., & Sommer, S. G. (2013). Validation and recommendation of methods to measure biogas production potential of animal manure. *Asian-Australasian Journal of Animal Sciences*, *26*(6). http://doi.org/10.5713/ajas.2012.12623

Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308.

Protection, U. S. E., & Agstar, A. (2011). Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures, (March).

Raposo, F., Banks, C. J., Siegert, I., Heaven, S., & Borja, R. (2006). Influence of inoculum to substrate ratio on the biochemical methane potential of maize in batch tests, *41*, 1444–1450. http://doi.org/10.1016/j.procbio.2006.01.012

Raposo, F., De la Rubia, M. a., Fernández-Cegrí, V., & Borja, R. (2012). Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews*, *16*(1), 861–877. http://doi.org/10.1016/j.rser.2011.09.008

Raposo, F., Fernandez-Cegri, V., de la Rubia, M. A., Borja, R., Beline, F., Cavinato, C., … de Wilde, V. (2011). Biochemical methane potential (BMP) of solid organic substrates: Evaluation of anaerobic biodegradability using data from an international interlaboratory study. *Journal of Chemical Technology and Biotechnology*, *86*(8), 1088–1098. http://doi.org/10.1002/jctb.2622

Rapport, J., Zhang, R., Jenkins, B., & Williams, R. (2008). *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste*. *IWMB-2008-0011*. California. Retrieved from http://www.calrecycle.ca.gov/publications/Detail.aspx?PublicationID=1275

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384. http://doi.org/10.1016/j.ecolecon.2003.10.017

Rodriguez Andara, A., & Lomas Esteban, J. M. (1999). Kinetic study of the anaerobic digestion of the solid fraction of piggery slurries. *Biomass and Bioenergy*, *17*, 435–443.

Rostow, W. (1960). *The stages of economic growth: a non-communist manifesto*. New york: Cambridge University Press.

Safferman, S. I., Kirk, D. M., Faivor, L. L., & Wu-haan, W. (2012). Anaerobic Digestion Processes. In *Bioremediation and Sustainability* (pp. 103–136). http://doi.org/10.1002/9781118371220.ch3

Sahlstr, L. (2003). A review of survival of pathogenic bacteria in organic waste used in biogas plants, *87*, 161–166.

Santos, V. E., Naval, L., Guardiola, E., & Lo, B. (1999). Kinetic model for anaerobic digestion of livestock manure, *25*, 55–60.

SAS Institute Inc. (2013). Cary, NC.

Scanlan, S. J. (2001). Guns, butter, and development: Security and military famine extensions of the modernization versus dependency debate. *Journal of Political & Military Sociology*, *29*(2), 331–355.

Schiffman, S. S., Studwell, C. E., Landerman, L. R., Berman, K., & Sundy, J. S. (2005). Symptomatic Effects of Exposure to Diluted Air Sampled from a Swine Confinement Atmosphere on Healthy Human Subjects. *Environmental Health Perspectives*, *113*(5), 567–76. http://doi.org/10.1289/ehp.6814

Schinasi, L., Horton, R. A., Guidry, V., Wing, S., Marshall, S., & Morland, K. (2011). Air Pollution, Lung Functions, and Physical Symptoms in Communities near concentrated Swine Feeding Operations.pdf. *Epidemiology*, *22*(2), 208–15.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford: Clarendon Press.

Skorov, G. (1973). The green revolution and social progress. *World Development*, *1*(11), 13–21.

Stromberg, S., Nistor, M., & Liu, J. (2014). Towards eliminating systematic errors caused by the experimental conditions in Biochemical Methane Potential (BMP) tests. *Waste Management*, *34*(11), 1939–1948. http://doi.org/10.1016/j.wasman.2014.07.018

Sunkel, O. (1969). National development policy and external dependence in Latin America. *Journal of Development Studies*. http://doi.org/10.1080/00220386908421311

Suryawanshi, P. C., Chaudhari, A. B., & Kothari, R. M. (2010). Mesophilic anaerobic digestion : first option for waste treatment in tropical regions, *30*(March), 259–282. http://doi.org/10.3109/07388551.2010.487047

Switzenbaum, M. S. (1995). Obtacles in the Implementation of Anaerobic Treatment

Technology. *Bioresource Technology*, *53*(95), 255–262.

Tafdrup, S. (1995). Viable Energy Production And Waste Recycling From Anaerobic Digestion Of Manure And Other Biomass Materials. *Biomass and Bioenergy*, *9*(95), 303–314.

Thompson, G. H. (2012). *A Macro-Comparative Analysis of Global Hunger across Developing Countries: The Integrative Impacts of Global and National Development, Gendered Inequalities, Conflict and Militarization, the Global Food System, and Environment. PhD Proposal*. North Carolina State University. http://doi.org/10.1017/CBO9781107415324.004

Toman, M. a. (1992). The difficulty in defining sustainability. *Rources*. http://doi.org/10.4324/9781936331642

Tomei, M. C., Braguglia, C. M., Cento, G., & Mininni, G. (2009). Modeling of Anaerobic Digestion of Sludge. *Critical Reviews in Environmental Science and Technology*, *39*(12), 1003–1051. http://doi.org/10.1080/10643380801977818

U.S. Environmental Protection Agency. (n.d.). Overview of Anaerobic Digestion and Digesters. Retrieved from http://www.epa.gov/region2/webinars/pdfs/3-24-10_1.pdf

United States Department of Agriculture. (2007). *Hog and Pig Farming*.

United States Department of Agriculture. (2014). *Biogas Opportunities Roadmap*. Retrieved from http://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf

United States Department of Agriculture, N. R. C. S. (2012). Agricultural Wastes and Water, Air , and Animal Resources. In *Agricultural Waste Management Field Handbook* (p. Part 651). USDA.

United States Department of Agriculture, & Department of Commerce. (1982). Census of Agriculture. http://doi.org/10.5962/bhl.title.18473

United States Department of Agriculture, & National Agricultural Statistics Service. Census of Agriculture, Pub. L. No. AC-12-A-51 (2012). United States.

United States Environmental Protection Agency. (1983). *Methods for Chemical Analysis of*

Water and Wastes. Cincinatti, OH.

US Department of Agriculture National Agricultural Service. (1988). Census of Agriculture. Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Department of Agriculture National Agricultural Service. (2014). Census of Agriculture.

US Department of Agriculture National Agricultural Service. (2015). Census of Agriculture. Retrieved August 10, 2016, from https://www.nass.usda.gov/Statistics_by_Subject

US Environmental Protection Agency. (1999). *Feedlots Point Source Category Study*. Retrieved from http://water.epa.gov/scitech/wastetech/guide/cafo/feedlots_index.cfm

Vanderholm, D., & Melvin, S. (2009). *Scraper Systems for Removing Manure From Swine Facilities*.

Vanotti, M., Szogi, A., Pilar Bernal, M., & Martinez, J. (2009). Livestock waste treatment systems of the future: a challenge to environmental quality, food safety, and sustainability. OECD Workshop. *Bioresource Technology*, *100*(22), 5371–3. http://doi.org/10.1016/j.biortech.2009.07.038

Vedrenne, F., Beline, F., Dabert, P., & Bernet, N. (2008). The effect of incubation conditions on the laboratory measurement of the methane producing capacity of livestock wastes. *Bioresource Technology*, *99*(1), 146–155. http://doi.org/10.1016/j.biortech.2006.11.043

Vos, R. O. (2007). Defining Sustainability: a conceptual orientation. *Journal of Chemical Technology & Biotechnology*, *82* (May), 334–339. http://doi.org/10.1002/jctb

Wallerstein, I. (1974). *The Modern World System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century.* New York, NY: Academic Press.

Weiland, P. (2010). Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology*, *85*(4), 849–60. http://doi.org/10.1007/s00253-009-2246-7

Williams, C. M. (2006). *Cost and Returns Analysis of Manure Management Systems Evaluated in 2004 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers*. Raleigh, NC.

Wing, S., & Wolf, S. (2000). Intensive livestock operations, health, and quality of life among eastern North Carolina residents. *Environmental Health Perspectives*, *108*(3), 233–238.

Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1637983/

World Bank. (2007). *World Development Report: Agriculture for Development.* Washington DC.

World Commision of Environment and Development. (1987). *Our Common Future*. *United Nations*. New York. http://doi.org/10.1080/07488008808408783

Yadvika, Santosh, Sreekrishnan, T. R., Kohli, S., & Rana, V. (2004). Enhancement of biogas production from solid substrates using different techniques--a review. *Bioresource Technology*, *95*(1), 1–10. http://doi.org/10.1016/j.biortech.2004.02.010

Yargeau, V. (2014). *Biomethane Potential (BMP) Assay Protocol*.

Yenigün, O., & Demirel, B. (2013). Ammonia inhibition in anaerobic digestion: A review. *Process Biochemistry*, *48*(5–6), 901–911. http://doi.org/10.1016/j.procbio.2013.04.012

APPENDICES

Appendix A

List of Countries used in Path Analysis (Chapter 2)

Afghanistan	Ghana	Norway
Albania	Greece	Oman
Algeria	Greenland	Pakistan
American Samoa	Grenada	Palau
Andorra	Guam	Panama
Angola	Guatemala	Papua New Guinea
Antigua and Barbuda	Guinea	Paraguay
Argentina	Guinea-Bissau	Peru
Armenia	Guyana	Philippines
Aruba	Haiti	Poland
Australia	Honduras	Portugal
Austria	Hong Kong SAR	Puerto Rico
Azerbaijan	Chin	Qatar
Bahamas	Hungary	Romania
Bahrain	Iceland	Russian Federation
Bangladesh	India	Rwanda
Barbados	Indonesia	Samoa
Belarus	Islamic Rep of Iran	San Marino
Belgium	Iraq	Sao Tome and Principe
Belize	Ireland	Saudi Arabia
Benin	Isle of Man	Senegal
Bermuda	Israel	Serbia (& Montenegro)
Bhutan	Italy	Seychelles
Bolivia	Jamaica	Sierra Leone
Bosnia and Herzegov	Japan	Singapore
Botswana	Jordan	Slovak Republic
Brazil	Kazakhstan	Slovenia

Brunei	Kenya	Solomon Islands
Darussalam	Kiribati	Somalia
Bulgaria	Dem. Rep. Korea	South Africa
Burkina Faso	Rep Korea	South Sudan
Burma	Kosovo	Spain
Burundi	Kuwait	Sri Lanka
Cambodia	Kyrgyz Republic	St. Kitts and Nevis
Cameroon	Lao PDR	St. Lucia
Canada	Latvia	St. Martin(Dutch p
Cape Verde	Lebanon	St. Martin(French p
Cayman Islands	Lesotho	St. Vincent and the
Central African Rep	Liberia	Sudan
Chad	Libya	Suriname
Chile	Liechtenstein	Swaziland
China	Lithuania	Sweden
Colombia	Luxembourg	Switzerland
Comoros	China Macao	Syrian Arab Republic
Dem. Rep of Congo	FYR Macedonia	Taiwan
Rep Congo	Madagascar	Tajikistan
Costa Rica	Malawi	Tanzania
Cote d'Ivoire	Malaysia	Thailand
Croatia	Maldives	Timor-Leste
Cuba	Mali	Togo
Curacao	Malta	Tonga
Cyprus	Marshall Islands	Trinidad and Tobago
Czech Republic	Mauritani	Tunisia
Denmark	Mauritius	Turkey
Djibouti	Mayotte	Turkmenistan
Dominica	Mexico	Turks and Caicos Is
Dominican Republic	Fed. St. Micronesia	Tuvalu
Ecuador	Moldova	Uganda

Egypt	Monaco	Ukraine
El Salvador	Mongolia	United Arab Emirate
Equatorial Guinea	Montenegro	United Kingdom
Eritrea	Morocco	United States
Estonia	Mozambique	Uruguay
Ethiopia	Myanmar	Uzbekistan
Faeroe Islands	Namibia	Vanuatu
Fiji	Nepal	Venezuela
Finland	Netherlands	Vietnam
France	New Caledonia	Virgin Islands
French Polynesia	New Zealand	West Bank and Gaza
Gabon	Nicaragua	Rep Yemen
Gambia	Niger	Zambia
The Republic of Georgia	Nigeria	Zimbabwe
Germany	Northern Mariana Is	

Appendix B

Raw data collected on MBP performed at 25°C

Temp: 25°C		Raw data of CH4 produced (mL) recorded												Ambient Temperature				Atmospheric Pressure	
														Left Side		Right Side			
Date	Time	R1-SS1	R2-SS2	R3-SS3	R4-SS4	R5-WS1	R6-WS2	R7-WS3	R8-WS4	R9-C1	R10-C2	R11-C3	R12-C4	In	Out	In	Out	altimer (in)	atm
5/29/16	10:22 PM	170	160	160	160	165	180	165	165	160	160	160	165	20.3	19.7	21.9	20.8	30.1	1.006
5/30/16	11:30 AM	230	235	210	205	220	235	260	215	195	185	190	190	20.7	20.7	21.6	21.2	29.99	1.002
5/30/16	2:56 PM	235	245	215	210	225	245	280	225	200	190	200	200	21.1	21.1	22.1	21.6	29.94	1.001
5/30/16	11:30 PM	250	270	230	230	235	255	320	235	210	200	210	210	20.8	20.6	22.1	21.2	29.95	1.001
5/31/16	10:20 AM	270	295	250	245	250	275	365	255	220	210	215	215	20.7	20.5	21.5	21.1	29.99	1.002
5/31/16	2:38 PM	275	305	255	250	260	285	385	260	225	215	215	220	21.3	21	22.4	21.7	29.94	1.001
5/31/16	8:04 PM	280	315	260	255	265	290	405	270	225	215	220	225	21.2	21	22.4	21.4	29.99	1.002
5/31/16	8:04 PM	280	315	260	255	265	290	215	270	225	215	220	225	21.2	21	22.4	21.4	29.99	1.002
6/1/16	10:30 AM	285	335	270	260	275	300	155	160	225	220	215	225	20.3	20.7	21.5	20.9	30.04	1.004
6/1/16	2:48 PM	290	345	280	265	280	310	210	195	225	225	220	225	21.2	20	22.2	21.4	30.04	1.004
6/1/16	7:45 PM	290	350	280	270	285	310	240	205	225	225	220	225	21.2	20.7	22.2	21.5	30.01	1.003
6/2/16	8:01 AM	295	360	290	275	295	325	295	235	225	225	215	220	20.6	20.1	21.6	21	30.08	1.005
6/2/16	2:03 PM	300	370	300	280	305	330	320	255	225	225	220	225	21.2	21.2	22.2	21.6	30.07	1.005
6/2/16	7:14 PM	305	395	310	285	310	340	345	270	225	235	220	225	21.5	21.2	22.8	22.1	30	1.003

6/3/16	8:40 AM	310	410	320	290	320	350	380	300	220	230	220	225	21.3	20.8	22.6	21.7	30.05	1.004
6/3/16	8:40 AM	310	210	320	290	320	350	380	300	220	230	220	225	21.3	20.8	22.6	21.7	30.05	1.004
6/3/16	3:03 PM	315	225	335	300	330	360	410	310	220	230	215	225	21.7	21.5	22.9	22.5	30	1.003
6/3/16	3:03 PM	315	225	335	300	330	360	200	310	220	230	215	225	21.7	21.5	22.9	22.5	30	1.003
6/3/16	7:30 PM	320	230	340	300	335	365	225	320	220	235	215	225	21.3	21.1	22.8	21.9	29.97	1.002
6/4/16	10:58 AM	325	260	350	310	345	375	270	350	215	235	210	220	22.2	22.4	23.2	22.7	30	1.003
6/4/16	3:18 PM	325	270	360	310	345	380	285	360	215	235	210	215	21.6	21.8	23	22.4	29.92	1.000
6/4/16	8:30 PM	325	280	365	315	350	385	300	370	210	240	210	215	21.8	21.5	23.1	22.1	29.9	0.999
6/4/16	8:30 PM	325	280	365	315	350	320	300	370	210	240	210	215	21.8	21.5	23.1	22.1	29.9	0.999
6/5/16	10:36 AM	325	300	375	320	365	325	325	395	205	235	210	210	22.1	21.9	23.1	22.6	29.87	0.998
6/5/16	4:23 PM	325	310	380	325	370	330	350	405	205	235	205	210	22	21.6	23.4	22.7	29.8	0.996
6/5/16	4:23 PM	325	310	380	325	370	330	350	205	205	235	205	210	22	21.6	23.4	22.7	29.8	0.996
6/5/16	7:00 PM	325	315	385	325	375	335	355	160	200	235	200	205	22.5	22.4	23.8	23	29.78	0.995
6/6/16	10:00 AM	310	330	385	320	380	340	385	160	190	220	190	195	21.3	21.3	22.9	22.9	29.87	0.998
6/6/16	3:00 PM	300	335	385	320	385	345	390	205	185	215	185	195	21.9	21.6	23.1	22.8	29.83	0.997
6/6/16	7:00 PM	300	335	385	320	390	350	400	215	185	215	185	190	21.7	21.5	23.2	22.6	29.79	0.996
6/6/16	7:00 PM	300	335	385	320	390	350	260	215	185	215	185	190	21.7	21.5	23.2	22.6	29.79	0.996
6/7/16	6:57 AM	280	350	375	310	395	355	275	235	175	200	175	180	20.8	20.6	22.4	21.5	29.68	0.992
6/7/16	2:28 PM	265	350	370	310	395	360	285	240	170	200	170	175	20.7	20.4	22.2	21.3	29.62	0.990
6/7/16	6:50 PM	260	350	365	305	400	360	290	245	170	195	170	175	20.1	19.9	22	21.2	29.62	0.990
6/7/16	6:50 PM	260	350	365	305	275	360	290	245	170	195	170	175	20.1	19.9	22	21.2	29.62	0.990
6/8/16	6:40 AM	230	340	340	285	255	350	290	250	155	175	155	160	19.4	19.2	21.2	20.2	29.83	0.997
6/8/16	2:00 PM	220	340	335	275	255	355	300	250	155	175	155	155	19.7	19.6	21.3	20.7	29.87	0.998

6/8/16	7:00 PM	215	340	325	275	260	350	300	255	0	0	0	0	19.9	19.8	21.4	20.8	29.87	0.998
6/9/16	9:07 AM	185	325	305	250	260	350	300	255	0	0	0	0	18.3	18.1	19.9	19.1	30.08	1.005
6/9/16	2:11 PM	180	325	305	250	260	355	305	260	0	0	0	0	19.2	19	20.3	19.9	30.03	1.004
6/9/16	7:04 PM	0	325	300	245	265	360	305	265	0	0	0	0	19.6	19.4	21	20.6	29.97	1.002
6/10/16	7:30 AM	0	315	290	230	265	360	295	265	0	0	0	0	18.7	18.5	20.3	19.7	30.11	1.006
6/10/16	2:00 PM	0	310	285	225	265	360	305	265	0	0	0	0	19.5	19.5	20.8	20.5	30.15	1.008
6/10/16	7:00 PM	0	310	285	225	270	360	305	270	0	0	0	0	20	19.8	21.2	20.6	30.08	1.005
6/11/16	9:42 AM	0	300	275	215	275	365	300	270	0	0	0	0	20.7	20.5	21.7	21.3	30.12	1.007
6/11/16	2:39 PM	0	295	275	215	280	370	300	275	0	0	0	0	20.7	20.2	21.9	21.2	30.07	1.005
6/11/16	7:50 PM	0	295	275	210	280	370	300	275	0	0	0	0	20.7	20.2	21.8	21.1	30	1.003
6/12/16	7:46 AM	0	285	270	205	285	375	300	280	0	0	0	0	21.2	20.9	22.6	21.9	29.99	1.002
6/12/16	2:02 PM	0	285	265	200	290	375	295	275	0	0	0	0	20.7	20.5	22.2	21.6	29.92	1.000
6/12/16	7:00 PM	0	280	260	200	295	375	295	280	0	0	0	0	21.2	20.8	22.6	21.7	29.85	0.998
6/13/16	8:35 AM	0	270	250	190	290	370	280	270	0	0	0	0	19.6	19.3	21.2	20.7	29.99	1.002
6/13/16	2:25 PM	0	270	250	185	290	370	280	270	0	0	0	0	20.1	19.7	21.4	20.9	29.96	1.001
6/13/16	7:24 PM	0	265	245	185	290	370	280	270	0	0	0	0	20.3	20	21.6	21.1	29.91	1.000
6/14/16	8:36 AM	0	250	230	175	290	360	270	260	0	0	0	0	19.7	19.4	21.1	20.6	29.96	1.001
6/14/16	2:00 PM	0	250	230	170	290	365	270	260	0	0	0	0	20.4	20.2	21.6	20.9	29.96	1.001
6/14/16	7:00 PM	0	250	230	170	295	365	270	255	0	0	0	0	20.6	20.2	21.8	20.9	29.9	0.999
6/15/16	8:14 AM	0	245	220	160	285	360	260	245	0	0	0	0	20.9	20.6	22.4	21.6	29.97	1.002
6/15/16	2:26 PM	0	245	220	0	290	360	260	240	0	0	0	0	22.4	22.2	23.2	22.9	29.93	1.000
6/15/16	7:12 PM	0	245	220	0	300	365	260	240	0	0	0	0	21.4	21.2	22.8	22	29.84	0.997
6/16/16	8:02 AM	0	240	210	0	300	365	260	230	0	0	0	0	21.3	21.2	23.1	22.9	29.79	0.996
6/16/16	7:00 PM	0	240	210	0	305	370	260	225	0	0	0	0	23.2	22.9	24.2	23.9	29.71	0.993

6/17/16	8:01 AM	0	240	200	0	300	365	255	220	0	0	0	0	23.3	23	24.7	24.5	29.75	0.994
6/17/16	2:07 PM	0	235	200	0	295	360	250	215	0	0	0	0	23.8	23.4	24.7	24.6	29.84	0.997
6/17/16	7:20 PM	0	230	195	0	290	360	250	210	0	0	0	0	23.4	23.2	24.5	24.2	29.91	1.000
6/18/16	9:05 AM	0	215	180	0	265	340	235	195	0	0	0	0	22.9	22.7	24	23.6	30.18	1.009
6/18/16	2:00 PM	0	215	175	0	260	330	230	190	0	0	0	0	23.2	23	24.2	23.9	30.23	1.010
6/18/16	7:00 PM	0	210	170	0	255	325	225	185	0	0	0	0	23.3	23	24.3	23.9	30.25	1.011

Denotes unit leaking

Denotes resetting volume down

Raw data collected on MBP performed at 35°C

Temp. 35C		Raw data of CH4 produced (mL) recorded												Ambient Temperature Left Side		Ambient Temperature Right Side		Atmospheric Pressure	
Date	Time	R1-SS1	R2-SS2	R3-SS3	R4-SS4	R5-WS1	R6-WS2	R7-WS3	R8-WS4	R9-C1	R10-C2	R11-C3	R12-C4	In	Out	In	Out	altimer (in)	atm
16-May	2:30 PM	175	155	175	155	180	165	-	165	170	155	155	155	18.4	16.9	18.2	17.7	30.23	1.010
16-May	11:19 PM	190	160	200	175	205	200	175	185	190	175	170	175	17.3	19.7	18.7	17.7	30.24	1.011
17-May	11:32 AM	195	160	205	175	205	200	175	190	195	180	175	175	17.7	17.3	18.7	18.1	30.21	1.010
17-May	3:33 PM	195	160	205	175	205	200	170	190	200	180	175	180	17.7	17	18.8	18.2	30.13	1.007
17-May	9:35 PM	210	170	210	185	220	210	170	200	205	190	185	190	17.6	17.1	18.8	18.1	30.11	1.006
18-May	11:10 AM	240	200	215	195	235	225	180	210	205	190	185	190	9.2	19.4	19.7	19.6	30.06	1.005
18-May	4:50 PM	250	215	220	200	240	230	185	220	205	190	185	190	21.1	21.1	21.3	21.2	30.04	1.004
18-May	9:46 PM	260	225	225	205	240	230	185	225	205	190	185	190	21.4	21.1	21.8	21.5	30.08	1.005

19-May	11:04 AM	280	240	240	215	250	240	190	230	200	185	180	185	22.2	21.8	22.7	22.4	30.14	1.007
19-May	2:59 PM	290	255	250	225	260	250	195	240	205	190	185	190	22.5	22.9	22.9	22.6	30.14	1.007
19-May	7:53 PM	300	260	255	230	265	255	195	245	205	185	180	190	22.2	21.8	22.9	22.5	30.18	1.009
20-May	10:20 AM	330	285	280	255	280	270	205	260	200	180	175	185	22.7	22.8	23.0	22.9	30.25	1.011
20-May	4:35 PM	335	290	285	265	280	275	205	265	195	175	175	180	19.2	18.7	20.5	19.9	30.15	1.008
20-May	9:41 PM	350	305	305	285	295	290	215	280	200	180	175	180	18.7	18.3	20.1	19.3	30.13	1.007
21-May	11:45 AM	375	330	335	325	320	315	230	305	195	175	175	180	18.5	18.4	19.8	19.4	29.94	1.001
21-May	4:53 PM	380	335	345	335	325	325	235	315	195	175	170	180	18.7	18.5	19.9	19.1	29.86	0.998
21-May	10:46 PM	385	340	350	340	335	335	245	325	195	175	170	175	18.6	18.2	19.9	19.0	29.86	0.998
22-May	11:45 AM	390	345	360	355	350	355	255	340	190	165	165	170	17.9	17.3	19.1	18.3	29.87	0.998
22-May	3:08 PM	390	345	360	355	355	355	255	340	185	165	165	170	17.8	17.3	19.0	18.4	29.86	0.998
22-May	10:20 PM	390	345	365	365	360	365	260	340	180	160	160	165	17.6	17.1	18.8	18.1	29.91	1.000
23-May	9:46 AM	395	350	375	375	380	370	280	345	180	160	155	165	20.7	20.7	21.5	21.1	29.96	1.001
23-May	3:15 PM	395	345	385	385	385	375	290	355	180	155	155	165	21.1	23.0	22.8	22.6	29.98	1.002
23-May	11:12 PM	380	330	380	380	380	370	295	350	170	150	150	155	19.2	19.7	20.2	20.0	30.04	1.004
24-May	12:21 PM	370	315	375	380	380	375	310	355	165	145	140	150	18.9	18.6	20.3	19.6	30.11	1.006
24-May	5:19 PM	365	310	375	375	380	380	315	355	165	145	140	140	18.9	19.6	20.0	19.3	30.08	1.005
24-May	9:57 PM	360	305	370	375	380	380	315	355	160	140	140	135	18.6	18.2	19.4	18.6	30.13	1.007
25-May	8:13 AM	345	290	360	365	380	385	310	360	160	135	135	140	18.0	17.7	18.5	18.0	30.22	1.010
25-May	1:27 PM	340	285	360	360	385	390	310	360	165	135	130	140	18.6	18.4	19.7	19.2	30.20	1.009
25-May	10:40 PM	335	280	355	355	385	390	310	360	165	130	130	140	19.6	19.3	20.8	20.0	30.17	1.008
26-May	9:40 AM	325	270	340	345	375	390	310	355	170	130	125	135	19.4	19.3	20.5	19.9	30.19	1.009
26-May	3:26 PM	325	270	340	340	375	390	315	355	170	120	130	135	20.2	20.1	21.5	20.8	30.11	1.006
26-May	9:50 PM	320	265	335	335	365	385	320	350	170	130	125	135	20.6	20.3	21.6	20.8	30.11	1.006

27-May	7:47 AM	305	255	325	325	355	380	320	340	170	125	120	130	19.7	19.4	20.9	20.3	30.16	1.008
27-May	5:01 PM	300	250	320	320	350	375	315	335	170	120	120	130	20.9	20.5	22.2	21.4	30.09	1.006

Raw data collected on MBP performed at 63°C

Temp: 63C		Raw data of CH4 produced (mL) recorded												Left Side		Right Side		Atmospheric Pressure	
Date	Time	R1-SS1	R2-SS2	R3-SS3	R4-SS4	R5-WS1	R6-WS2	R7-WS3	R8-WS4	R9-C1	R10-C2	R11-C3	R12-C4	In	Out	In	Out	altimer (in)	atm
25-Apr	6:00 PM	150	170	160	160	170	150	170	170	150	160	150	170	24.8	24.6	25.3	25.0	29.96	1.001
25-Apr	10:12 PM	230	240	230	230	270	265	255	260	225	230	230	230	24.8	24.6	25.3	25.0	29.97	1.002
26-Apr	9:30 AM	260	280	260	250	290	295	275	300	230	225	250	240	25.4	25.7	25.8	25.7	29.97	1.002
26-Apr	2:05 PM	270	290	265	260	300	300	280	305	235	225	250	240	19.6	19.4	20.1	19.8	29.89	0.999
26-Apr	5:27 PM	275	290	270	265	300	300	280	305	235	225	250	240	25.4	24.7	26.0	25.3	29.83	0.997
26-Apr	10:02 PM	275	290	270	265	300	300	280	305	230	220	240	230	24.4	24.2	25.2	24.8	29.82	0.997
27-Apr	9:34 AM	260	285	255	255	280	285	260	285	220	215	235	215	17	17	17	17	29.88	0.999
27-Apr	2:00 PM	265	290	265	260	285	285	260	290	220	220	240	225	21	21	21	21	29.83	0.997
27-Apr	7:40 PM	270	290	270	260	290	290	260	290	220	220	240	225	26.7	27.3	26.9	26.8	29.82	0.997
27-Apr	10:45 PM	270	290	270	260	290	285	260	290	220	220	245	225	26.8	26.5	27.1	26.9	29.86	0.998
28-Apr	9:38 AM	260	280	255	250	280	280	250	280	210	210	230	215	26.7	26.9	27.2	26.9	29.93	1.000
28-Apr	1:46 PM	260	280	255	250	280	280	250	280	210	210	235	220	28.2	27.7	28	28	28.89	0.966
28-Apr	3:13 PM	260	280	255	250	280	280	250	280	210	210	235	220	28.2	28.7	28.5	28.3	29.87	0.998
28-Apr	5:50 PM	255	275	250	240	270	275	240	275	210	210	230	215	26.4	23.7	26.8	24.9	29.85	0.998
28-Apr	10:20 PM	250	265	245	235	270	270	235	265	200	200	225	210	23.8	24.9	25.2	24.7	29.89	0.999
29-Apr	9:48 AM	240	265	240	225	260	260	225	265	195	195	220	200	25.9	26.3	26.4	26.7	30	1.003

29-Apr	2:21 PM	240	265	235	225	260	260	225	265	190	195	220	205	25.8	24.3	26.9	25.7	29.99	1.002
29-Apr	4:52 PM	235	265	230	220	255	260	220	260	190	195	220	200	23.3	22.7	24.7	24	29.94	1.001
29-Apr	11:06 PM	230	260	220	210	245	250	210	250	180	180	205	190	21.7	20.5	23	22	29.99	1.002
30-Apr	8:31 AM	235	260	215	205	240	245	205	245	175	175	200	185	23.4	24.4	23.9	23.4	30.13	1.007
30-Apr	3:35 PM	240	265	215	200	240	240	200	245	170	175	200	185	24.4	25.4	25.4	25.4	30.13	1.007
30-Apr	6:35 PM	240	265	210	200	235	240	200	240	175	175	200	185	25.2	25.1	25.7	25.6	30.13	1.007
30-Apr	10:48 PM	245	265	210	200	230	235	200	240	175	175	200	185	25.1	24.8	25.6	25.6	30.16	1.008
1-May	11:08 AM	240	260	200	180	225	225	190	230	165	165	185	175	25.4	25	25.6	25.8	30.11	1.006
1-May	3:07 PM	240	260	205	190	225	225	190	230	170	170	190	180	26	26.5	26.1	26.4	30.06	1.005
1-May	5:17 PM	240	260	205	190	225	225	190	230	170	170	190	180	27.1	26.8	26.8	27	30.06	1.005
1-May	9:49 PM	235	255	200	185	220	220	185	230	160	165	180	175	26.8	26.8	27	27.1	30.06	1.005

Appendix C

Manure characteristics data collected by Murphy Brown on 2014 (Analysis Chapter 3).

Sample Date	Weeks in Finisher	Solids Volume (gal)	Liquid Volume (gal)	Total Waste Collected (gal)	Waste per head (gpd)	Water Usage per head (gpd)
1/7/14	16.9	279.8	N/A	279.8	--	N/A
2/18/14	1.9	138.7	799.2	937.9	1.24	1.46
3/25/14	6.9	214.5	769.8	984.3	1.62	2.39
4/24/14	11.1	213.4	1133.9	1347.3	2.30	2.84
6/3/14	16.9	131.2	601.2	732.4	1.51	2.38

		January	February	March	April	June	Average
	Number of hogs (head)	1266	1313	1267	1248	1013	1221
	Retention time between data collection	36.75	42	35	30	40	36.75
Scraped Solids	Waste (L/head/day)	1.67	0.8	1.28	1.29	0.98	1.2
	VS content (kg/day/1,000 finishing pigs)	57.32	14.54	N/A	36.47	27.55	32.66
	VS kg/month/1,000 finishing pigs	2106.51	610.68	N/A	1094.1	1102	1228.32
	CH4 produced per loading (L/loading) - 35C	625633.47	181371.96	N/A	324947.7	327294	364811.7825
	CH4 produced per loading (L/loading) - 25C	587716.29	170379.72	N/A	305253.9	307458	342701.9775
Whole Slurry	Waste (L/head/day)	N/A	5.41	5.88	8.17	5.47	6.23
	VS content (kg/day/1,000 finishing pigs)	N/A	38.14	N/A	79.87	84.56	67.52
	VS kg/month/1,000 finishing pigs	N/A	1601.88	N/A	2396.1	3382.4	2460.13
	CH4 produced per loading (L/loading) - 35C	N/A	435711.36	N/A	651739.2	920012.8	669154.4533
	CH4 produced per loading (L/loading) - 25C	587716.29	170379.72	N/A	305253.9	307458	342701.9775