AGRICULTURE RESILIENCE ACT

Workshop in Applied Earth Systems Management

COLUMBIA | SIPA
School of International and Public Affairs

THE EARTH INSTITUTE
COLUMBIA UNIVERSITY



ACKNOWLEDGEMENTS

Workshop in Applied Earth Systems Management, Summer 2020

Manager
Abigail Edwards

Deputy Manager
Emily Becker

Members
Alyssa Ramirez
Charles Saad
Danna Creager
Gwen Macchione
Louiza Molohides
Rebecca Purba

Faculty Advisor
Dr. Matthew Palmer

COLUMBIA | SIPA
School of International and Public Affairs

THE EARTH INSTITUTE
COLUMBIA UNIVERSITY

Photo Credits

Page 1: Kees Streefkerk/Unsplash, Ricardo Gomez Angel/Unsplash, Jean Carlo Emer/Unsplash. Page 5: Abigail Edwards. Page 7: Our World in Data. Page 8: Kees Streefkerk/Unsplash. Page 10: Caroline Aitken/Whitefield Permaculture. Page 11: United States Department of Agriculture/NRCS. Page 13: Pace et al./Utah State University. Page 14: United States Department of Agriculture/NRCS. Page 16: Greig Cranna/Earthbound Farm. Page 17: Julian Hochgesang/Unsplash. Page 18: Ricardo Gomez Angel/Unsplash. Page 20: United States Department of Agriculture/National Institute of Food and Agriculture. Page 21: Rocky Mountain Research Station (RMRS)/USDA Forest Service Page 22: Jason Leung/Unsplash. Page 24: Don Jenkins/Capital Press. Page 26: Vanguard Renewables/United States Environmental Protection Agency. Page 27: Vanguard Renewables/United States Environmental Protection Agency. Page 28: Jean Carlo Emer/Unsplash. Page 32: Steffan Mitchell/Unsplash.

CONTENTS

EXECUTIVE SUMMARY

Agriculture is among the leading contributors to global greenhouse gas emissions. In the United States, it is a particularly significant contributor to emissions, contributing 585 million gigatons of greenhouse gases annually, roughly 9% of the country's total emissions. Importantly, agriculture is the leading source of US methane emissions, a greenhouse gas that is 25 times more potent than carbon dioxide, contributing nearly 40% of the country's methane emissions. If the United States hopes to address its sizable contributions to global greenhouse gas emissions and, by extension, climate change, it must substantially reform the agriculture sector.

At the same time, climate change also poses a substantial risk to food production due to its impacts on global temperatures and water availability. As our planet changes, it is imperative that we develop a more resilient and adaptive agriculture sector that can weather these uncertain and rapidly evolving conditions.

The Agriculture Resilience Act of 2020 (H.R. 5861), introduced by Congresswoman Chellie Pingree (D-ME), addresses greenhouse gas emissions from American agriculture while building a more resilient and sustainable agricultural system. The bill proposes a series of sweeping reforms across the agricultural sector, including changes to livestock production, crop production, agricultural waste management, and on-farm energy. In reforming these practices, the bill simultaneously addresses the immediate environmental impacts of agriculture, including air and water pollution, as well as the long term effects of greenhouse gas emissions. To mitigate agriculture's environmental impacts, the bill includes an ambitious greenhouse gas reduction target: 50% from the 2010 levels by 2030 and net-zero by 2040. Additionally, the bill's actions would increase American agriculture's resilience to climate change.

Programs proposed in the Agriculture Resilience Act include investment in on-farm renewable energy, the promotion of efficient and environmentally sound waste management practices, and the development of public livestock breeds and crop cultivars that could lower environmental impacts or improve future yields. Each of these proposed solutions would both reduce greenhouse gas emissions and increase agricultural resilience. Through research, the implementation of new technologies, and the promotion of long-established sustainable agriculture management methods, the Agriculture Resilience Act creates a framework for the redesign of American agriculture.

Though expansive, it can be argued that the solutions put forth in this bill will not achieve the bill's set goal of net-zero carbon emissions in the allocated time frame. If implemented, the Agriculture Resilience Act would develop substantial infrastructure on farms to encourage the use of environmentally sound agricultural practices — but it is unclear whether these changes could reduce greenhouse gas emissions quickly enough to meet the aggressive timeline. That said, the solutions put forth in this bill would make substantial reductions to carbon and methane emissions from agriculture, suggesting that it may be, at the very least, a significant first step on the path towards a resilient, carbon-neutral or carbon-negative agriculture system in the United States.

INTRODUCTION

In the United States, agriculture is a leading contributor to greenhouse gas emissions and the primary source of methane emissions (EPA, 2020). Methane is 25 times more potent than carbon dioxide and a key driver for global climate change (EPA, 2011). As our planet warms and local climates change, agricultural production will become increasingly challenging as farms face more regular threats from natural disasters and adverse weather conditions. If the United States hopes to mitigate its contribution to greenhouse gas emissions and protect its ability to produce food, it must significantly reduce or eliminate greenhouse gas emissions from all sectors, with a particular emphasis on methane emissions from agriculture. The Agriculture Resilience Act of 2020 (H.R. 5861) proposes a series of reforms to the US agricultural system to mitigate greenhouse gas emissions from the sector while making it more resilient to ongoing climate change. The bill, proposed by Representative Chellie Pingree (D-ME) addresses a wide range of both global and local environmental challenges:

- Soil carbon depletion and diminished agricultural productivity
- Agricultural land use and deforestation
- Methane emissions from enteric fermentation
- Methane emissions and environmental pollution from livestock waste management

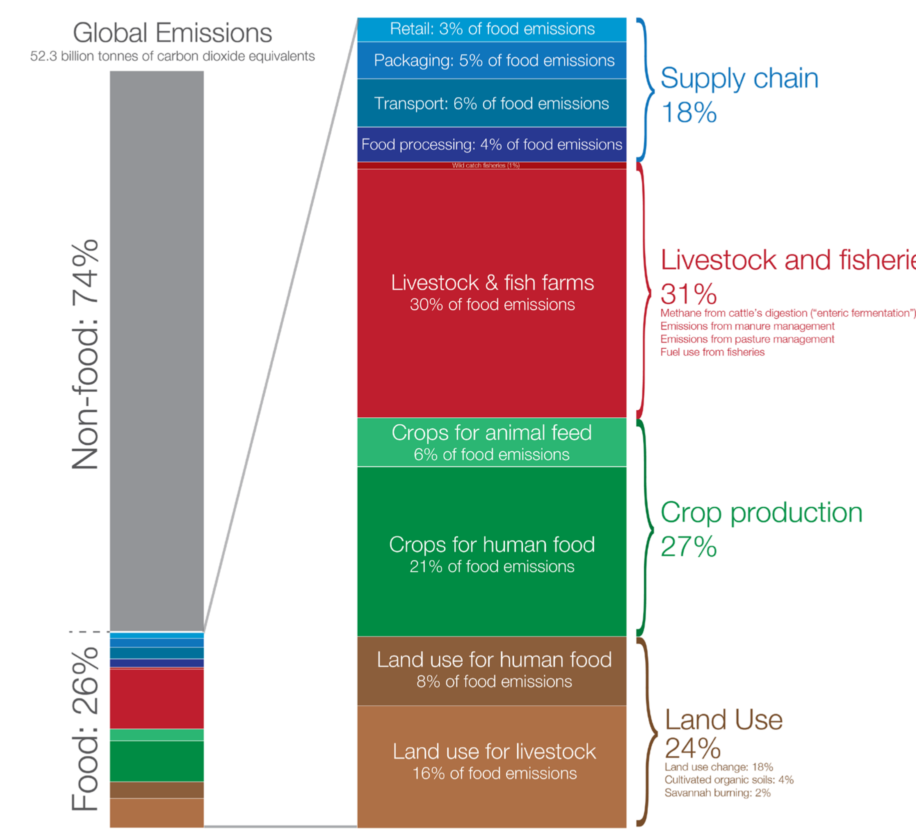
Each of these problems has substantial implications for greenhouse gas emissions and consequent implications for the sustainability of future agricultural production. In response to these and other challenges, the Agriculture Resilience Act advances a set of changes to agricultural practices, research topics, and grant programs. The bill's proposed changes to agricultural practices include the increased use of no-till agriculture, cover crops, rotational grazing, agroforestry, and manure-fueled anaerobic digesters. The bill proposes substantial investment in research on inefficiencies in agriculture, carbon sequestration, and on the development of new public breeds and cultivars. The bill aims to integrate sustainable practices and research across the agricultural system in order to preserve the United States' ability to produce nutritious food in the face of increasingly unpredictable weather conditions and a warming climate.

BACKGROUND

26%

of global greenhouse gas emissions come from food production
(Ritchie, 2019)

Agriculture is fundamentally challenging practice: agricultural production is impacted by changes in weather, natural disasters, threats to crop and livestock health, and changing consumer desires. Climate change, which will affect the frequency and intensity of natural disasters like droughts and major storms, threatens to make agriculture even more challenging in the years to come. At the same time as it is impacted by climate change, agriculture also contributes to climate change. 26% of global greenhouse gas emissions come from food production (Ritchie, 2019). The largest agricultural source of greenhouse gas emissions is livestock production (including fisheries), contributing 31% of global agricultural emissions coming from enteric fermentation and livestock waste. The remaining 70% of agricultural greenhouse gas emissions are divided among crop production (27%), land use (24%), and retail, packaging, and transport (18%). The Agriculture Resilience Act aims to reduce greenhouse gas contributions from agriculture with a target goal of net-zero greenhouse gas emissions by 2040. The bill proposes a number of changes to US agriculture to achieve this goal, including the implementation of sustainable livestock and soil management systems, the expansion of agricultural research programs, and the promotion of on-farm renewable energy.



Global greenhouse gas emissions on food production

I
SOIL MANAGEMENT

The Problem: Soil Management

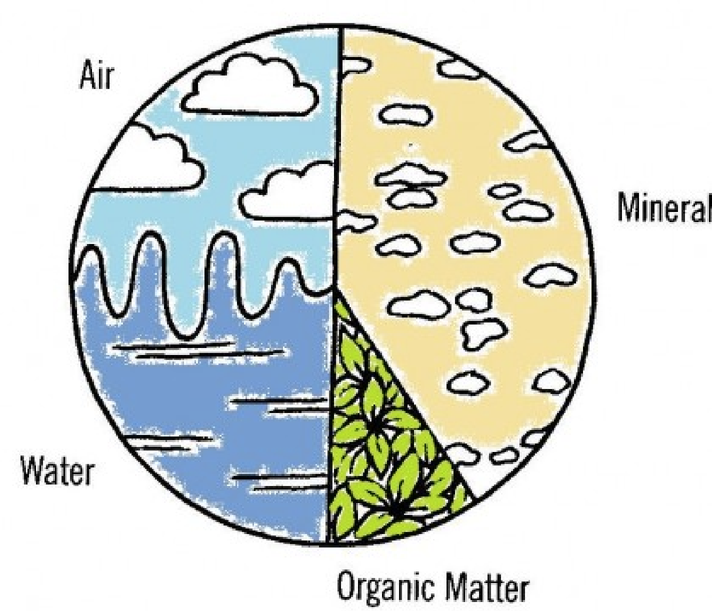
Over 50% of land in the U.S. is devoted to agricultural use so understanding the co-dependent relationship between agriculture and soil is essential in evaluating the impact of agriculture on the environment (United States Department of Agriculture, 2019). Soil is a complex system dependent on the interactions between chemical, biological, and physical processes. When the soil is altered for cultivation, these processes are disrupted in ways that can cause significant environmental harm. Agricultural practices such as monoculture, cropping without the use of a fallow period, and tillage affect the carbon in the soil by exposing the organic matter in soil to oxygen. Upon exposure to oxygen, the organic matter decomposes, releasing carbon dioxide into the atmosphere and depleting the carbon stock in soils. The loss of organic matter influences both soil structure and function by decreasing soil fertility and increasing the risk of erosion. As erosion through either wind or water increases, soil is lost. Indeed, the current estimated rate of erosion is 4.6 tons per acre per year, resulting in significant national soil losses each year (Office of Science and Technology Policy, White House, 2016). Soil loss not only diminishes the fertility of agricultural land, but also decreases water absorption, exacerbating floods, and affecting nutrient cycling (Killebrew, 2010).

> *Over 50% of land in the United States is devoted to agricultural use so understanding the co-dependent relationship between agriculture and soil is essential in evaluating the impact of agriculture on the environment.*

THE SCIENCE BEHIND THE PROBLEM

Soil Composition and Structure

Soil is composed of both solid matter and pore space. In a typical agricultural soil, solid matter is approximately 45% mineral and 5% organic matter; the remaining 50% is pore space which is variably filled with water and air (Natural Resources Conservation Service, n.d.). Pore space is essential for the exchange of water and air — both necessary for biological processes such as fungal, bacterial, and plant growth. Soil organic matter consists of decomposed plant and animal matter (Brady and Weil, 2010). This organic matter is crucial for almost every natural process in the soil, providing a number of physical benefits including increased water holding capacity and aeration, chemical benefits such as increased nutrient supply and nutrient availability, and biological benefits such as providing food for organisms and enhancing microbial diversity and function (Fenton et al., 2008). Because soil organic matter is composed of carbon, it is a vital component of soil carbon sequestration. Soil organic matter also influences soil structure, acting like glue between soil particles to form soil aggregates. Multiple soil aggregates then form the soil's overall structure. A suitable soil structure for plant growth has distinct aggregates, separated by ample pore space for water and gas exchange (Brady and Weil, 2010). Without adequate organic matter, soil cannot maintain plant growth and agricultural production.



Healthy Soil Composition

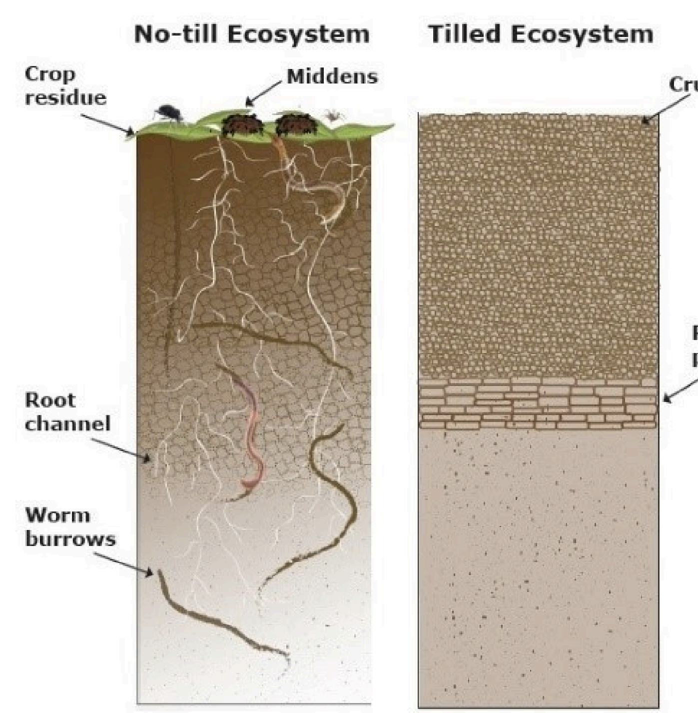
Agricultural Impacts

1.85 Pg/year

of carbon can potentially be sequestered by cropland from the atmosphere globally (Brady and Weil, 2010)

Globally, cropland has the potential to sequester between 0.90 and 1.85 Pg/year of carbon from the atmosphere (Brady and Weil, 2010, Zomer et.al., 2017). Through photosynthesis, vegetation converts atmospheric CO_2 to biomass, which then dies and enters the soil. This process causes carbon that was previously in the atmosphere to incorporate into the soil in the form of soil organic matter. Microbial decomposition of soil organic matter then releases CO_2 back into the atmosphere (Cho, 2019). When production through photosynthesis exceeds this decomposition, soil carbon storage increases.

Tillage is the act of mechanically disturbing the soil, typically done with a plow or cultivator for the purpose of preparing the soil for crop production (Brady and Weil, 2010). Tillage breaks apart soil aggregates, weakens soil structure, and aerates the soil, stimulating aerobic microbial decomposition of soil carbon and, in so doing, releasing CO_2 into the atmosphere (Halvin et al., 2014). Tillage also accelerates soil erosion, which limits agricultural productivity (Brady and Weil, 2010, Halvin et al., 2014). To compensate for lost productivity, farmers often supplement tilled fields with fertilizer and the production of this fertilizer also generates substantial carbon emissions.



Till vs No-Till System

A majority of agricultural management systems rely on mechanized agricultural practices, in particular, heavy farm equipment for plowing (Brady and Weil, 2010). Plowing and other practices compact the soil, which reduces pore space and restricts water percolation to lower horizons (Brady and Weil, 2010). As tillage compacts soil, soil aggregates break apart, exposing more of the soil organic matter to microbes. These microbes then consume the soil organic matter and, subsequently, respire CO_2 into the atmosphere. Additionally, soil compaction reduces pore space, making it difficult for plant roots to gain access to water and nutrient sources (Halvin et al., 2014).

Though they may contribute to increased short term yields, mechanized soil management practices clearly reduce soil health and long term productivity, while contributing substantially to CO_2 emissions.

PROPOSED SOLUTIONS

Composting

Composting is an active waste management process characterized by moist, self-heating, and aerobic conditions to create a stable material that can be used as organic fertilizer (Lobo & Dorta, 2019). It is an effective solution to provide carbon sequestration (Lobo & Dorta, 2019). There are several common composting systems, each suitable for different timelines, and waste conditions including:

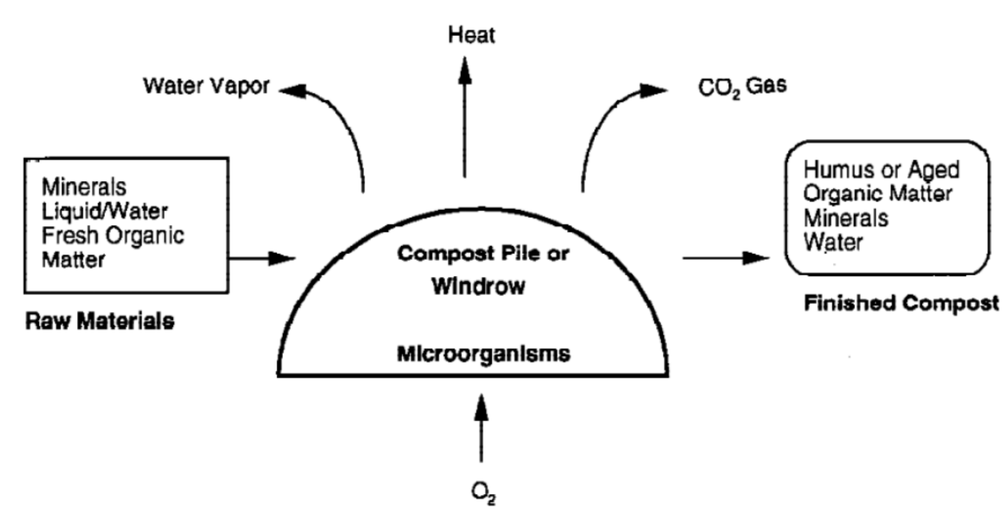
- *Onsite Composting:* On-site composting is a small-scale, low equipment strategy, but it can require anywhere from six months to two years to create a usable fertilizer (US EPA, 2016).
- *Vermicomposting:* Earthworms interact with microorganisms to stabilize organic matter. The technology used in vermicomposting is simple and requires little initial investment while creating relatively low levels of secondary pollution (Lobo & Dorta, 2019).
- *Aerated static pile composting (rapid composting):* In this technique, organic waste is mixed in a large pile aerated by loosely stacked bulking agents such as wood chips or shredded newspaper (US EPA, 2016). This process can take as little as three to six months to produce a final fertilizer product and success is closely tied to climatic and seasonal conditions (US EPA, 2016).
- *Aerated Windrow Composting:* This method is typically employed on large farms and involves the creation of long rows of organic waste called "windrows", which are then mechanically or manually aerated (US EPA, 2016). This process may be applied at a larger scale, but it also requires substantial land area
- *In-Vessel Composting:* Organic matter is fed into a drum or silo and mechanically mixed to aerate (US EPA, 2016). This process can accommodate large amounts of waste with less land use and works quickly, producing fertilizer in a matter of weeks or months. In-vessel composting is more expensive than other methods and requires specialized expertise to operate the equipment (US EPA, 2016).

At the conclusion of these processes, farmers will have produced a high-nutrient fertilizer and significantly reduced on-farm greenhouse gas emissions.

The Science of Composting

Though composting methods vary in terms of required equipment, cost, and time commitment, the same core process takes place in each composting system. Composting breaks down raw organic materials into humus, the organic matter within soil that contributes to soil health and productivity (Cooperband, 2002). This process occurs when raw organic materials are mixed together in the presence of microbes. These microbes — primarily fungi and bacteria — are quite diverse and their functions are affected by temperature. Temperature change generally follows a pattern of increase to around 120-140ºF from initial ambient temperature, and these elevated temperatures are maintained by the heat released from the decomposition for a certain period of time — often several weeks — depending on the materials being processed (Pace, 1995). As temperatures change, different bacteria, fungi, and other small organisms are active and differentially break down a broad range of compounds within organic material. As different substrates are consumed decomposition slows down and the temperature gradually decreases until the compost reaches ambient temperatures.

There are several factors that impact the effectiveness of the composting process such as aeration, carbon to nitrogen ratio of the feedstock, moisture, particle size, and time. If the supply of oxygen in the compost environment is limited, the composting process may turn anaerobic, which slows the process. A deficit of the nutrients microorganisms use for energy and growth may also negatively impact the composting process. Microorganisms use carbon for energy and use nitrogen for protein production and reproduction. An appropriate ratio of carbon and nitrogen (C:N ratio) — between 20:1 and 40:1 — is recommended for a faster composting process (Graves, 2000). Additionally, a moisture level from 40-65% is necessary to support the metabolic processes of the microbes (Pace, 1995).



The science of composting

The rate of aerobic decomposition increases with smaller particle sizes (Pace, 1995). The length of time required to transform raw materials into compost depends on the aforementioned conditions, but, under the right circumstances, composting may take place rapidly and efficiently (Pace, 1995).

Reduced Tillage and Other Soil Management Techniques

In order to reduce microbial respiration of CO_2 farmers may elect to significantly reduce tillage and, instead, employ a system of low-till or no-till agriculture that limits exposure of soil organic matter to oxygen (Cho, 2019). A reduction in how often or how intensively cropland is tilled enables the soil to retain more organic matter, which leaves the soil less susceptible to erosion and helps maintain carbon storage.

Alternatively, farmers can improve soil fertility by using fallow periods, crop rotation, or cover crops. A fallow period is a window in the growing season when the land is not producing crops in order to let the soil rest and regenerate (Lobo & Dorta, 2019). Crop rotation is the process by which different crops are grown sequentially in the same area through different growing seasons. By rotating the crops on the same land, soil nutrients are not depleted by repeated growth of the same crops and soil health is improved (Lobo & Dorta, 2019). If properly planned and executed, cover crops will also protect farmland by reducing soil erosion.

Use of Cover crops to reduce tillage impacts in New York

Research Centers

The bill proposes investment in research to expand scientific understanding of sustainable agricultural practices and identify inefficiencies in existing agricultural practices. This research will be performed through a network of research centers called the Long-Term Agroecological Research Network. Research at these centers will focus on the development of new sustainable farming practices and opportunities for emissions reductions. Areas of study include:

- *On-farm Methane Emission Capture*
- *Soil Carbon Measurement and Carbon Sequestration*
- *Livestock Systems and Manure Management*
- *Sustainable Agriculture (i.e. Agroforestry)*
- *Public Breeds and Cultivars*
- *Soil Health Enrichment*

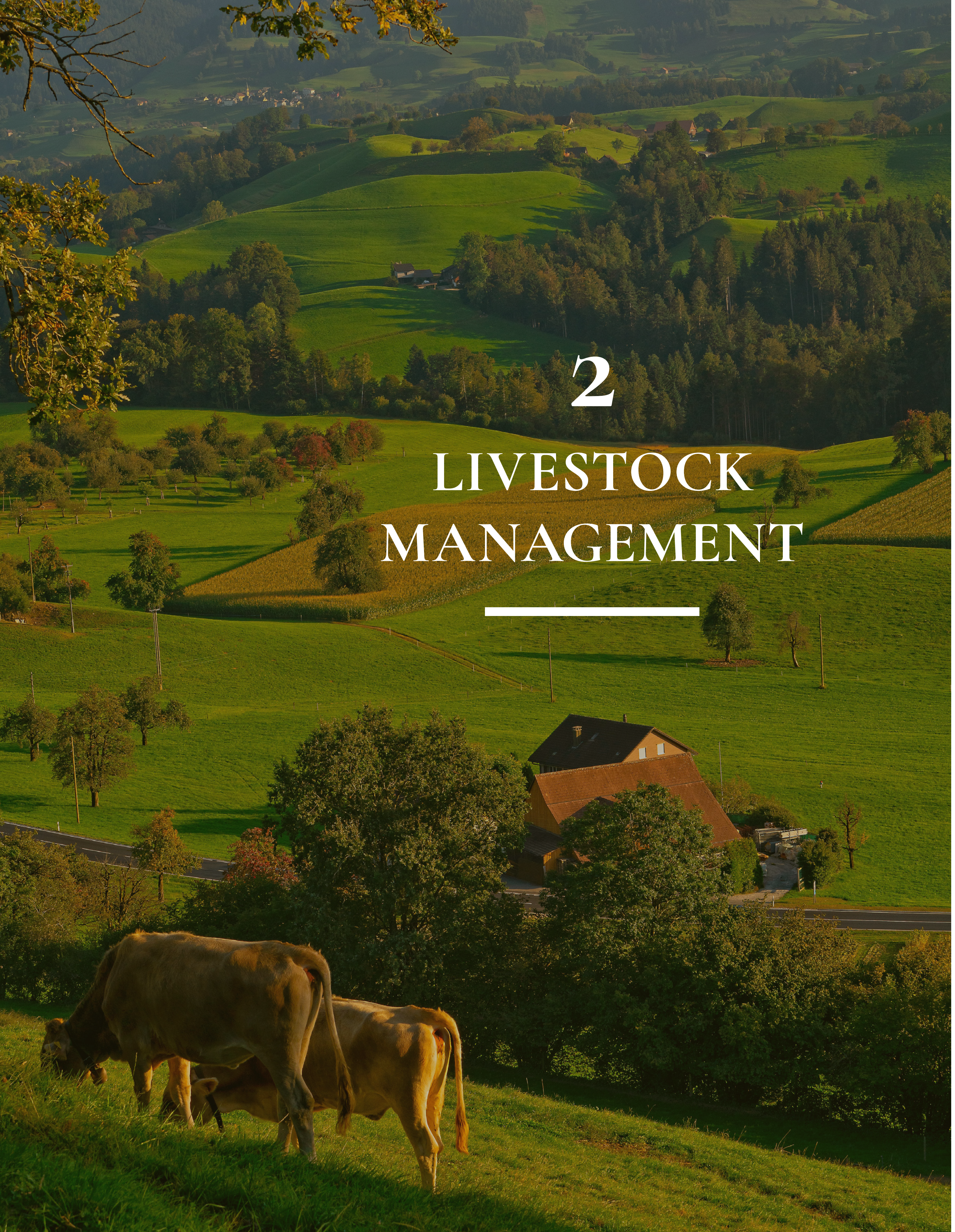
Expanding technologies for methane emission capture has the potential to, if successful, make a substantial contribution towards achieving net-zero greenhouse gas emissions from agriculture. Additionally, the existing approaches to measuring carbon sequestration potential measurement are laborious and expensive (Donovan, 2011). Improving carbon sequestration measurements will assist climate scientists and policymakers in their efforts to understand the relationship between soil and the changing climate. Further studies on livestock systems and manure management on farms will identify opportunities for integrated sustainable management (Montes et al., 2013). Research on the integration of agriculture and forestry can increase biodiversity on agricultural land while building ecosystem resilience and improving soil health (USDA, 2016). Research on new public breeds and cultivars will help farmers adapt to a changing climate. Finally, research on soil management practices would include the enrichment of soil health through livestock rotation with advanced grazing practices.

CASE STUDY: SOIL CARBON IMPROVEMENT

Michael Brautovich and Bella Colfer own Earthbound Farms, one of the nation's largest growers of fresh salad mix and organic vegetables. Earthbound and its network of cooperative farmers cultivate approximately 30,000 acres of fruits and vegetables in California, Arizona, and Northern Mexico (CalRecycle, 2013). As their business has expanded, Michael and Bella have begun using between three and ten tons per acre of compost feed, integrating compost at the very beginning or end of the cropping season. Michael and Bella work closely with permitted California compost production facilities to ensure that all compost meets the farm's standards. Earthbound only applies compost with a pH between 6.5 and 8.5 and a carbon-to-nitrogen ratio of less than 17:1, in order to maximize the benefits of this compost. A third-party authority works with composters by testing procedures based on the US Compost Council's Test Methods for the Examination of Composting and Compost; they work together to review process-water testing, feedstock separation, temperatures, curing procedures, and overall sanitation (CalRecycle, 2013). The careful monitoring of compost conditions and chemistry allows Earthbound to improve its soils while limiting the contamination of its soil by foreign pathogens.

When the final product is delivered to one of Earthbound's fields, it is tilled in right away. Michael and Bella are confident through their data from soil testing that they are building soil organic matter over time, and cite compost and its contributions to soil organic matter as integral components of their farm's operations.

Earthbound Farm in San Juan Bautista, California



The Problem: Livestock Management

Animal agriculture is the second-largest contributor to global greenhouse gas emissions, falling just behind fossil fuel combustion (Gerber et al., 2013). Globally, livestock production is a leading cause of deforestation, water pollution, air pollution, and a loss of biodiversity (Gerber et al., 2013). Feeding, watering, and maintaining livestock places enormous strain on many of the Earth's finite natural resources. In order to accommodate the 70 billion animals raised annually for human consumption, a third of the planet's ice-free land surface, as well as nearly 16% of global freshwater, is devoted to growing livestock (Foley et al., 2011). Furthermore, about 40% of global crop calories are used to feed livestock (Pradhan et al., 2013).

PROPOSED SOLUTIONS

How livestock are raised in the United States has an impact on greenhouse gas emissions. These emissions can be reduced through solutions like rotational grazing, integrated crop-livestock cultivation, and agroforestry.

Rotational Grazing

In rotational grazing systems, livestock are moved between pastures on a regular basis which mimics an animal's natural grazing behavior (Morgan 2012). This intensifies the consumption of forage in a particular area within a specific paddock while allowing other areas to recover from grazing. Relatively short but intense grazing allows the roots of perennial plants to remain intact so the plants can regrow after grazing. The soil in rotational grazing situations is improved by having manure and urine dropped all across the pasture as the animals are moved, rather than concentrated in a single location around a feeding station or watering hole. Additionally, the hooves of the livestock produce natural tillage of the soil as they move around the pasture. This works nutrients from manure and urine into the soil where it can feed the forage plants. The exact details of a rotational grazing system will vary based on local conditions but overall the practice has been recognized as an effective way to sequester carbon in the soil (Anderson, 2019).

Integrated Crop-Livestock Cultivation

Integrated crop-livestock cultivation is the combination of livestock and crop agriculture in a single farm. This more closely mimics natural ecosystems than does conventional agriculture. There are several methods for integrating crops and livestock. One is to plant cover crops on fields used for crop production and allow livestock to graze on the cover crops. Alternatively, after crops are harvested, livestock can be allowed to graze on the crop residue still in the field (Lemaire at al., 2014). In both these cases, the dropping of manure and urine onto the field and subsequent integration of the manure into the soil by hooves trap carbon in the soil. Additionally, there is also the practice of allowing certain types of livestock to graze in fields while the crops are growing. Some breeds of livestock, such as the cotton patch goose, were created for the express purpose of grazing within staple crop fields. In the case of the cotton patch goose, the geese would be introduced to cotton patches in the American south after cotton plants became established. They would then consume both weeds and insects which threaten the crop. After the cotton was harvested, the geese would be slaughtered and either eaten or sold to provide an additional source of income for the farmer (Livestock Conservancy, 2020).

Mixed crop-livestock systems: changing the landscape of organic farming. Palouse, Washington

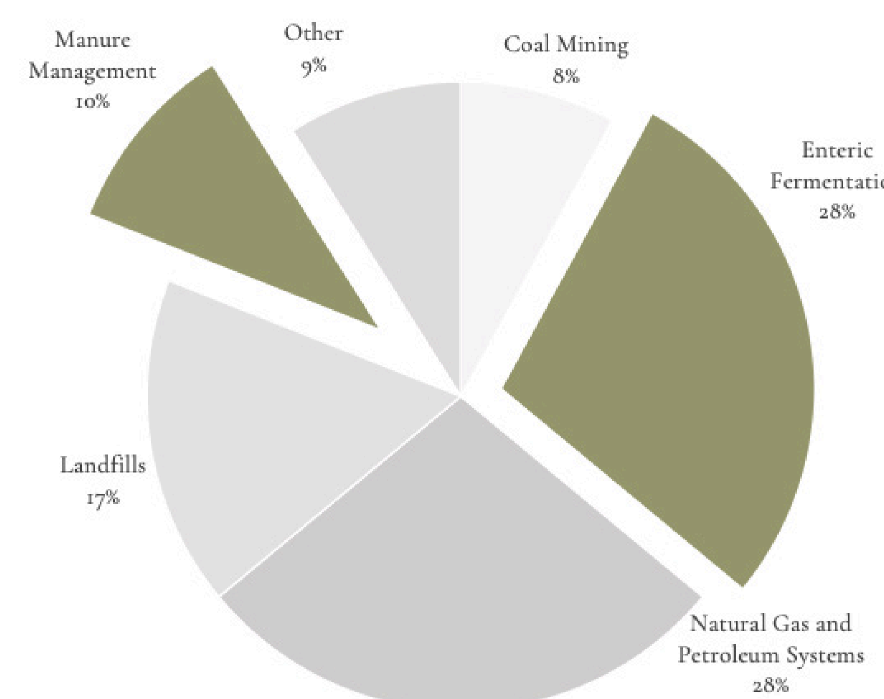
Agroforestry

Agroforestry mimics the ecosystems found in forested areas and covers various practices such as silvopasture, forest farming, and alley cropping (USDA, 2016). Silvopasture combines livestock and tree or shrub cultivation. The trees and shrubs provide shade for the livestock and the livestock graze upon low growing plants and nuts and fruits which have fallen from the trees. Forest farming is practiced by planting food, herbal, or decorative crops under a forest canopy. This can provide additional income for farmers as several crops are grown in forested areas that may not have otherwise produced cash crops. Alley cropping is the cultivation of crops between rows of trees or shrubs. The trees and shrubs provide shade for shade-loving crops, provide protection from wind, and prevent erosion. Agroforestry can store from five to ten times as much carbon per hectare as other agricultural land uses (Toensmeier, 2016).

An agroforestry technique known as lley cropping. Flagstaff, Arizona

The Problem: Livestock Waste

In 2018, manure management — how manure is captured, stored, treated, and used — represents 10% of total methane emission in the United States (EPA, n.d.). These emissions are generated by microorganisms that consume the nutrients in livestock waste and, as they do so, emit methane gas. Because methane is an enormously potent greenhouse gas (25 times more so than carbon dioxide), these emissions are particularly damaging. Additionally, nutrients found in animal waste can act as environmental pollutants. Phosphorus and nitrates contained in manure can support the spread of waterborne pathogens and the growth of algae blooms (Cox, 2019). These blooms can poison wildlife by starving the water of oxygen and release neurotoxins which can enter the food chain with eventual consumption by humans (Cox, 2019). Furthermore, improperly stored livestock waste may result in the contamination of local drinking water sources, as well as the spread of airborne pollutants, resulting in a substantial community health risk (Gerber et al., 2013).



2018 United States Methane Emissions by source

Manure Management

Current management practices frequently place manure in open-air vessels, including lagoons, settling pits, ponds, and slurry tanks. In these nutrient-rich environments, bacteria break down compounds such as carbohydrates, proteins, and fatty acids down into carbon dioxide and methane (Climate and Clean Air Coalition, n.d.). This decomposition has two primary phases: first, bacteria known as acid formers oxidize the organic substrates in waste, producing acetate as they do so. This biochemical intermediary is then either converted directly into methane by methane-producing bacteria known as methanogens or converted into carbon dioxide and then, in the presence of hydrogen gas, reduced to form methane (Jones, n.d.).


Liquid manure in storage

PROPOSED SOLUTION

Anaerobic Disgestion

Anaerobic digestion is the biological process through which bacteria break down organic matter in the absence of oxygen. This process converts organic material into digestate or biosolids and biogas. Digestate, a nutrient-rich substance, can be used as a fertilizer or soil amendment, while biogas is a mixture of gases, consisting primarily of carbon dioxide and methane (Ciborowski, 2001). These gases may be used to generate electricity on-site or can be purified and supplied to a natural gas distribution system. The collection and use of methane generated from livestock manure offer the potential to reduce methane emissions from livestock production by harnessing waste-byproducts that might otherwise be released from an open-air waste storage setting. These closed digester systems have the added benefit of reducing odor, air pollution, and water contamination from waste storage and management from livestock waste (Ciborowski, 2001). Anaerobic digestion can also reduce emissions that would be generated transporting the waste in vehicles using fossil fuels. Given its potential use as a biogas generator, livestock waste represents an untapped resource. Anaerobic digestion allows farmers to reap environmental and economic benefits from the waste management process.

The Science Behind Anaerobic Digestion

Anaerobic digestion is the process of the sequential degradation of complex organic molecules to smaller and smaller forms. Hydrolytic, acidogenic, acetogenic, and methanogenic bacteria are involved. These four sets of bacteria correspond to the four stages of anaerobic digestion: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (detailed below, from Ciborowski 2001).

Stage 1, Hydrolysis:
This is the process through which bacteria, using enzymes, break down complex organic compounds to simpler forms and make them available for use by other bacteria. The products of hydrolysis are simple sugars, amino acids, peptides, and long-chain fatty acids.

Stage 2, Acidogenesis:
The products of hydrolysis then undergo acidogenesis. At this stage, these lower weight molecules are taken through the cell walls of acidogenic bacteria and metabolized to short-chain fatty acids like acetic acid, carbon dioxide, hydrogen gas, and ammonia.

Stage 3, Acetogenesis:
The products of acidogenesis are broken down further in acetogenesis. At this stage, bacteria catabolize or degrade short-chain fatty acids and reduce carbon dioxide using hydrogen, resulting in acetate.

Stage 4, Methanogenesis:
Acetate produced during acetogenesis is then broken down further forming methane and carbon dioxide in the final process of methanogenesis.

CASE STUDY: ANAEROBIC DIGESTER USE

Bar-Way Farm

Deerfield, Massachusetts, family owned 600-acre dairy farm

More than 250 dairy cows produce 1,700 gallons of milk a day

Other agriculture products: straw, hay, butternut squash, pumpkins, and garlic

Steven Melnik and his son, Peter, own and operate the Bar-Way Farm that was founded in 1919 in Deerfield, MA. They are committed to producing high-quality milk sustainably and profitably. Through a partnership with Vanguard Renewables, they successfully achieve their sustainability goal by using an anaerobic digester at the farm. Other than processing livestock manure, the Bar-Way Farm digester also addresses food waste problems in the surrounding area by accepting organic material from supermarkets, restaurants, institutions, and food manufacturers nearby.

Inside the tank, there are two mixers, which push waste down into the center of the tank, preventing sediment accumulation and buildup. The tank is topped by a pair of insulated rubber domes that inflate when methane gas is produced as the manure and food waste undergoes anaerobic digestion. The operation of the anaerobic digester is controlled and monitored by a computer system.

The digester generates enough methane to fuel a 1-megawatt electricity generator and also generates 1.62 million BTU per hour of heat that is used by the facility and the farm. Additionally, over 26,000 gallons of liquid effluent are generated daily providing a high value, odor-free fertilizer that is then used on the farm's crops.

Bar-Way Farm in Deerfield, Massachusetts

Benefits to the environment

Reduces emissions and produces enough energy to power 900 homes

Reduces the use of petrochemical fertilizers by producing organic fertilizer

Annually diverts 36,500 tons of food waste from landfills

Bar-Way Farm anaerobic digester

CONTROVERSIES

The fundamental controversy at the heart of this bill is the extent to which the bill's proposed solutions will accomplish the goal of net-zero emissions from agriculture by 2040. The pace of global warming is rapid and solutions intended to mitigate emissions must advance quickly to address this threat. There is some disagreement as to whether the solutions proposed in the bill can actually achieve this goal, with particular controversy surrounding anaerobic digesters and the scale of potential soil-carbon sequestration. However, it is important to note that the American agriculture system is vast, heterogeneous, and slow moving. It will be exceptionally challenging to arrive at net-zero carbon emissions from agriculture by 2040. Even with net-zero emissions in the agricultural sector, the scale of other emissions may still generate substantial climate repercussions; consequently, change to the agricultural sector must be accompanied by a broader, economy-wide reduction in greenhouse gas emissions.

Emissions from Manure Management

On-farm anaerobic digesters have the potential to capture greenhouse gases for productive use: instead of allowing waste to decay in open-air environments and, in so doing, emit large quantities of methane, on-farm digesters harness gases from animal waste to create valuable biogas (Klavon et al., 2013). Though anaerobic digesters use existing animal waste to create energy, the use of this technology will still release greenhouse gases. Burning biogas for energy and the flaring of waste gas both emit greenhouse gases, though they are admittedly less potent than the methane emitted by open-air livestock waste storage (U.S. Department of Energy, 2019).

After anaerobic digestion, digestate may continue to release residual methane via offgassing during storage prior to use as fertilizer (Paolini et al., 2018). Anaerobic digesters may reduce on-farm greenhouse gas emissions by approximately 23%, assuming standard digestate storage methods; however, these reductions jump to approximately 36% when a gas-tight tank is used for digestate storage (Battini et. al, 2014). A 36% reduction in emissions is substantial, but, if these results are generalizable when applied to other systems, anaerobic digestion infrastructure alone would not bring livestock waste management to the bill's overall net-zero goal.

Activist groups are divided on the utility of anaerobic digesters for livestock waste management. The Environmental Defense Fund argues that the substantial methane emissions reductions achieved through anaerobic digester use justifies the creation of additional greenhouse gas emitting infrastructure (EDF, 2019). By contrast, Food and Water Watch suggests that the creation of biogas infrastructure only reinforces the United States' commitment to industrial agriculture, a system they consider inherently emissions-intensive (Food and Water Watch, 2019). Ultimately, the group suggests, the only way to dramatically reduce or eliminate greenhouse gas emissions is to shift away from industrial farming in the United States.

Soil Carbon Storage

Soil carbon sequestration is commonly touted as an underused approach to reducing atmospheric CO_2 concentrations with the added benefit of improving soil structure and agricultural productivity. Although it is undeniable that soil carbon sequestration confers significant benefits, policy makers often overstate soil's ability to sequester carbon without recognizing the limits of the system. Soils will eventually become saturated with carbon, meaning they can no longer absorb additional carbon (Cho, 2018). The point at which soil arrives at saturation depends on climate, soil type, and soil management strategies, but all soils will eventually achieve carbon saturation. Inaccurate estimates of soil carbon sequestration capacity are due, in large part, to insufficient models. Commonly used soil carbon sequestration models assume a linear relationship between carbon inputs and carbon storage, neglecting both the eventuality of saturation and the impact of soil type, climate, and management on storage capacity (Stewart et al., 2007). Consequently, soil's carbon storage potential is of time-limited (though substantial) benefit. In order to maximize the efficacy of soil carbon storage, land management practices would need to undergo substantial and long term changes, making soil carbon sequestration a more challenging and time-intensive emissions reduction strategy than may be adequate to combat the shorter-term effects of the climate crisis.

MEASURING SUCCESS

The U.S. agricultural industry is a major source of food both domestically and internationally. With so much of the world's population dependent on the United States' agricultural output, the success of the bill, decreasing greenhouse gas emissions from the agricultural sector, cannot come at the expense of agricultural production. It is essential that the success of the bill's programs are measured to ensure that goals are met while maintaining production.

Agricultural Output

Determining any changes in agricultural output in response to programs enacted by the bill is simplified by the fact that the United States Department of Agriculture produces an annual crop production summary. This report includes data on crop acreage, production, and yield. Data are gathered from a survey of farmers in the United States. While it would be impractical to survey every farmer in the country, the USDA attempts to survey a representative sample of the farming population. In 2019, the USDA surveyed 79,000 farmers, almost 4% of US farmers (USDA, 2020). The USDA also maintains records of livestock production including herd size, livestock demographics, and outputs such as milk, eggs, and meat.

The size of the United States poses a challenge for measuring the success of the bill's programs. For example, one region of the country may be in a drought while another is flooding. However, the USDA records data on the county level (USDA, 2020). This makes it possible to compare the effectiveness of programs as they go into effect in various areas of the country. The impact that farms that have switched to silvopasture or crop-livestock integration have on output can be viewed at smaller scales when appropriate and not lost in the national data.

Carbon Accounting

The bill has a goal of 50% reduction in net 2010-level greenhouse gas emissions by 2030. By 2040 the bill mandates that the agricultural sector achieve net-zero emissions. The Environmental Protection Agency already collects data on emissions from every sector, including agriculture. These data are then utilized to produce an annual report on greenhouse gas emissions.

The major greenhouse gas emissions from agriculture are methane, nitrous oxide, and carbon dioxide. These emissions primarily come from soil management, enteric fermentation, manure management, field burning of agricultural residues, liming, and urea fertilization (EPA, 2019). To gather data on these emissions the EPA coordinates with federal agencies such as the USDA, the National Oceanic and Atmospheric Administration, and the US Geological Survey. Additionally, academic research centers as well as private companies assist in the collection of emissions data for the EPA. Once the data are collected, the EPA coordinates the annual methodological choice, data collection, emission calculations, and quality assurance and quality control processes (EPA, 2019). After the total emissions for each greenhouse gas are calculated the emissions of various gasses are converted into CO_2 equivalents. CO_2 equivalents are reported in million metric tons (CDP, 2020). The EPA then compiles the data and calculations into a report (EPA, 2019).

5 CONCLUSIONS

Reducing greenhouse gas emissions from climate change is a monumental task. Agriculture in the United States is a vast industry, representing approximately 5.5% of the United States gross domestic product (USDA, 2020). There are substantial infrastructure and entrenched processes surrounding agricultural production and distribution. Emissions-intensive agricultural processes (i.e. waste storage lagoons, confined livestock facilities, etc.) are central to the current structure of American agriculture. In order to reduce emissions resulting from the agriculture and food systems, substantial changes to agricultural production will be necessary.

The solutions put forth in the Agriculture Resilience Act constitute a substantial restructuring of American agriculture to balance the health of the environment with agricultural productivity, rather than prioritizing productivity and profit above all else. The Agriculture Resilience Act proposes expanded use of emissions-reducing methods and technologies, including anaerobic digesters, composting, and reduced tillage practices. Additionally, the Act aims to establish a network of research centers, focused on the advancement of low-emissions agricultural technologies and the creation of public breeds and cultivars. The Act also promotes investment in on-farm renewable energy.

Through a combination of emissions-reducing technologies and practices, in addition to extensive research, the Agriculture Resilience Act pushes the US agricultural system towards net-zero emissions by 2040. It is imperative that reductions to emissions take place without dramatic changes to productivity, if the United States is to continue feeding its citizens. The success of the Agriculture Resilience Act can be measured by cross-referencing annual crop production data from the United States Department of Agriculture with greenhouse gas emissions data collected by the Environmental Protection Agency. Together, these data will allow policymakers to determine whether the Act's proposed changes will reduce greenhouse gas emissions without sacrificing agricultural productivity.

The Agriculture Resilience Act will — if implemented appropriately — lead to substantial greenhouse gas emissions reductions from agriculture. While this report has explored both the specifics of the Act and its implications for greenhouse gas emissions, there are aspects of its implementation that have not yet been considered: the feasibility of these changes, the extent to which these changes will reduce greenhouse gases, and the consequences for agricultural productivity and revenues. From a scientific standpoint, however, it is clear that the solutions put forth in the Agriculture Resilience Act represent an important step forward for emissions reductions in the United States.

REFERENCES

Battini, F., Agostini, A., Boulamanti, K., Amaducci, S., and Giuntoli, J. (2014). "Mitigating the Environmental Impacts of Milk Production via Anaerobic Digestion of Manure: Case Study of a Dairy Farm in the Po Valley." *Science of The Total Environment*, vol. 481, May 2014.

Berendes, D., Yang, P., Lai, A., Hu, D., and Brown, J. (2018). "Estimation of Global Recoverable Human and Animal Faecal Biomass." *Nature Sustainability*, Nature Sustainability, Nov. 2018

Brady, N., and Ray, W. (2010). *Elements of the Nature and Properties of Soils*. Prentice Hall, 2010.

Briske, D., Brown, J., Derner, J., and Fuhlendorf, S. (2008). Rotational grazing on rangelands: Reconciliation of perception and experimental evidence. *Rangeland Ecology and Management*, 61(1), 2008.

CalRecycle. (2013) "Case studies on compost use in agriculture". Retrieved from http://www.calrecycle.ca.gov/organics/farming/CaseStudies/default.htm

Carbon Disclosure Project. (2020) "Full Greenhouse Gas Emission Dataset 2019".CPD. Carbon Disclosure Project, 23 January 2020. Web. https://6fefcbb86e61af1b2fc4-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/comfy/cms/files/files/000/003/025/original/2020_01_06_Full_GHG_Emissions_Dataset_Summary.pdf

Cho, R. (2018)."Can Removing Carbon From the Atmosphere Save Us From Climate Catastrophe?" *State of the Planet.* https://blogs.ei.columbia.edu/2018/11/27/carbon-dioxide-removal-climate-change/.

Cho, R. (2019). "Can Soil Help Combat Climate Change?" *State of the Planet*. Columbia University Earth Institute, 06 Feb. 2019. Web. https://blogs.ei.columbia.edu/2018/02/21/can-soil-help-combat-climate-change/.

Ciborowski, P. (2001).Anaerobic Digestion of Livestock Manure for Pollution Control and Energy Production: A Feasibility Assessment. https://www.pca.state.mn.us/sites/default/files/p-gen4-02.pdf

Climate and Clean Air Coalition. "Livestock and Manure Management." *Climate & Clean Air Coalition*, www.ccacoalition.org/en/activit y/livestock-and-manure-management.

Congressional Research Service. *U.S. Forest Carbon Data: In Brief* (R46313). Congressional Research Service, 2020, https://crsreports.congress.gov/product/pdf/R/R46313.

Cox, D. (2019)."The Planet's Prodigious Poo Problem." The Guardian, Guardian News and Media, 25 Mar. 2019, www.theguardian.com/news/2019/mar/25/animal-waste-excrement-four-billion-tonnes-dung-poo-faecebook.

Cruz, A. (2017). "Flipping the Issue: Agriculture Contributes to Climate Change?" Flipping the issue: agriculture contributes to climate change? World Agroforestry Centre, 19 Aug. 2017. Web.

De Meester, S., Penne, A., Velghe, F., and Demeyer, J. (2012)."The Environmental Sustainability of Anaerobic Digestion as a Biomass Valorization Technology." *Bioresource Technology*, vol. 121, Oct. 2012, pp. 396–403.

Donovan, P. (2011) "Measuring Soil Carbon and Soil Change: A flexible, practical, local method." https://soilcarboncoalition.org/files/MeasuringSoilCarbonChange.pdf

Eshel, G., Shepon, A., Noors, E., and Milo, R. (2016). "Environmentally Optimal, Nutritionally Aware Beef Replacement Plant-Based Diets." ACS Publications, American Chemical Society, 7 July 2016, pubs.acs.org/doi/abs/10.1021/acs.est.6b01006.

Montes, F., et al.(2013). SPECIAL TOPICS — Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options, *Journal of Animal Science*, Volume 91, Issue 11, November 2013, Pages 5070–5094,

Foley, J., et al. (2011). "Solutions for a Cultivated Planet." Nature News, Nature Publishing Group, 12 Oct. 2011, www.nature.com/articles/nature10452.

Gerber, P., Henning, S., and Benjamin H. (2013). "Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities." Food and Agriculture Organization of the United Nations, 2013. Web.

Halvin, J., et al. (2014). *Soil Fertility and Fertilizers. Eighth*, Pearson, Inc.

Livestock Conservancy. (2020). "Integrated Crop-Livestock Systems." *Integrated Crop-Livestock Systems | Department of Agronomy and Horticulture | Nebraska*, 2020, agronomy.unl.edu/range-pasture-forages/integrated-crop-livestock-systems.

Integrated Crop-Livestock Systems. (2012). Rethink Agriculture. https://rethinkag.wordpress.com/integrated-crop-livestock-systems/

Jones, D., et al. "Methane Generation From Livestock Waste." *AE-105*, Purdue University Department of Agricultural Engineering, www.extension.purdue.edu/extmedia/ae/AE-105.html.

Kassel, K. and Rosanna M. (2019)."Ag and Food Sectors and the Economy." *United States Department of Agriculture*, https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/#:~:text=What%20is%20agriculture's%20share%20of,about%201%20percent%20of%20GDP.

Killebrew, K. and Wolff, H. (2010). "Environmental Impacts of Agricultural Technologies."

Klavon, K., Lansing, S., Mulbry, W., Moss, A. and Felton, G. (2013)."Economic Analysis of Small-Scale Agricultural Digesters in the United States." *Biomass and Bioenergy*, vol. 54, Mar. 2013, pp. 36–45.

Lemaire, G., Franzluebbers, A., Carvalho, P., and Dedieu, B. (2014). Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agriculture, Ecosystems & Environment, 190, 4–8. https://doi.org/10.1016/j.agee.2013.08.009

Lobo, M.G. and Dorta, E. (2019). Utilization and Management of Horticultural Waste. *Postharvest Technology of Perishable Horticultural Commodities* (pp. 639-666). Woodhead Publishing.

Natural Resources Conservation Service. (2020)."Soil Does More Than Get You Dirty - A Soil Recipe| NRCS Kansas." *Natural Resources Conservation Service*. N.p., n.d. Web. 11 June 2020. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ks/newsroom/factsheets/?cid=nrcs142p2_033595

Office of Science and Technology Policy, White House. (2016). "Framework for a Federal Strategic Plan for Soil Science." *THE STATE AND FUTURE OF U.S. SOILS*, Dec. 2016. Subcommittee on Ecological Systems, *Committee on Environment, Natural Resources, and Sustainability*.

Paolini, V., and et al. (2018)."Environmental Impact of Biogas: A Short Review of Current Knowledge." *Journal of Environmental Science and Health*, vol. 53, no. 10.

Pradhan, P., et al. (2013)."Embodied Crop Calories in Animal Products." IOP Science, IOP Publishing Ltd, iopscience.iop.org/article/10.1088/1748-9326/8/4/044044.

Ramirez-Islas, M., Guereca, P., Sosa-Rodriguez, F. and Cobos-Peralta, M. (2020). "Waste Management." *Waste Management*, vol. 102, Feb. 2020, pp. 85–96.

Ritchie, H. "Food Production Is Responsible for One-Quarter of the World's Greenhouse Gas Emissions." *Our World in Data*, 6 Nov. 2019, ourworldindata.org/food-ghg-emissions.

Sharvelle, S., and Loetscher, L. (2011). Anaerobic Digestion of Animal Wastes in Colorado. Colorado State University. https://extension.colostate.edu/docs/pubs/livestk/01227.pdf

Stewart, C., et al. (2007). Soil carbon saturation: concept, evidence and evaluation. *Biogeochemistry* 86, 19–31. https://doi.org/10.1007/s10533-007-9140-0

Teague,W., et al.(2010). Soil and herbaceous plant responses to summer patch burns under continuous and rotational grazing. Agriculture, Ecosystems, and Environment. Vol 137, p113-123. April 15, 2010.

Toensmeier, E.(2016). *The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security* (F First Edition Used edition). Chelsea Green Publishing.

United States Department of Agriculture. (2016). *Agroforestry Horizons:Experiences and Reflections*. United States Department of Agriculture. April 27, 2016. https://www.fs.usda.gov/nac/assets/documents/resources/conference-proceedings/agroforestry-horizons/AF-HorizonsReportOutFinal.pdf

United States Department of Agriculture. " Cover Crops: Keeping Soil in Place While Providing Other Benefits". https://www.nrcs.usda.gov/wps/portal/nrcs/main/ny/technical/.

United States Department of Agriculture (2020). "Crop Production 2019 Summary." *National Agricultural Statistics Service*, USDA, Jan. 2020, www.nass.usda.gov/Publications/Todays_Reports/reports/cropan20.pdf.

United States Department of Agriculture. (2019). "Major Land Uses." United States Department of Agriculture Economic Research Service, https://www.ers.usda.gov/topics/farm-economy/land-use-land-value-tenure/major-land-uses/.

United States Department of Agriculture. "USDA Agroforestry Strategic Framework: Fiscal Year 2019-2024." *Agroforestry*, USDA, www.usda.gov/topics/forestry/agroforestry.

United States Department of Agriculture. (2020)."USDA - National Agricultural Statistics Service - Data And Statistics - Livestock County Estimates." https://www.nass.usda.gov/Data_and_Statistics/County_Data_Files/Livestock_County_Estimates/index.php.

United States Department of Energy. (2019). *Natural Gas Flaring and Venting: State and Federal Regulatory Overview, Trends, And Impacts*. U.S. Department of Energy, June 2019.

United States Environmental Protection Agency. (2020) "Inventory of U.S. Greenhouse Gas Emissions and Sinks." *EPA*, Environmental Protection Agency, 13 Apr. 2020, www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

United States Environmental Protection Agency. "Greenhouse Gas Emissions". *EPA*. Environmental Protection Agency, n.d. Web. https://www.epa.gov/ghgemissions/overview-greenhouse-gases#:~:text=In%202018%2C%20methane% 0(CH4,sources%20such%20as%20natural%20wetlands.

United States Environmental Protection Agency. (2019). How does anaerobic digestion work?: United States Environmental Protection Agency. https://www.epa.gov/agstar/how-does-anaerobic-digestion-work.

United States Environmental Protection Agency. (2012). “Inventory of U.S. Greenhouse Gas Emissions And Sinks: 1990 – 2010”. *EPA*. Environmental Protection Agency, 15 Apr. 2012. Web. https://www.epa.gov/sites/production/files/2015-12/documents/us-ghg-inventory-2012-main-text.pdf.

United States Environmental Protection Agency. (2019). “Inventory of U.S. Greenhouse Gas Emissions And Sinks: 1990 – 2017”. EPA. Environmental Protection Agency, 11 Apr. 2019. Web. https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf.

United States Environmental Protection Agency. (2011). *Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures.* U.S. Environmental Protection Agency AgSTAR Program, Mar. 2011, https://www.epa.gov/sites/production/files/2014-12/documents/protocol.pdf.

United States Environmental Protection Agency. (2004). *Risk Assessment Evaluation for Concentrated Animal Feeding Operations.* https://nepis.epa.gov/Exe/ZyPDF.cgi/901V0100.PDF?Dockey=901V0100.PDFU.S.

United States Environmental Protection Agency. (2016). Types of Composting and Understanding the Process: United States Environmental Protection Agency Sustainable Management of Food. https://www.epa.gov/sustainable-management-food/types-composting-and-understanding-process

Veenstra, J., “Fifty years of agricultural soil change in Iowa.” Graduate Theses and Dissertations. 11428, 2010. https://lib.dr.iastate.edu/etd/11428

Watts, J.” World’s food supply under ‘severe threat’ from loss of biodiversity.” The Guardian, 2019.

Midterm Briefing

Click here to watch or scan the QR code below

Agriculture Resilience Act - Emily Becker

Final Briefing

Click here to watch or scan the QR code below

Agriculture Resilience Act- Charlie Saad

AGRICULTURE RESILIENCE ACT

Workshop in Applied Earth Systems Management
Summer 2020

COLUMBIA | SIPA
School of International and Public Affairs

THE EARTH INSTITUTE
COLUMBIA UNIVERSITY