Global Warming, A Student Review


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Abstract

Global warming continues to be discussed and debated. While this discussion continues, atmospheric carbon dioxide gradually rises and is now at 413 mg kg⁻¹, the highest level recorded since 1958, and an increase of 24% (315 to 413) in the last 62 years (NASA, https://climate.nasa.gov/vital-signs/carbon-dioxide/).

Students in an advanced nutrient management class were assigned specific topics based on their interests as it relates to challenges present that surround Global warming. Results highlighted several findings, including increased incidence of wildfires, perils of aerosols, the value of moving to plant-based diets, and the importance of government policy, especially from the developed world.

A summary statement appropriate from this student review would be that a shocking level of public resistance remains, even in the light of having overwhelming evidence of documented sources of anthropogenic contamination coming from fossil fuels, soil organic matter, nitrous oxide, and the animal industry.

Abbreviations: GHG, Greenhouse gases; C, Carbon; N, Nitrogen; P, Phosphorus; K, Potassium; Ca, Calcium, Mg, Magnesium; NASA, National Aeronautical and Space Administration; CFC, chlorofluorocarbons; HFC, hydrofluorocarbons; IPCC, Intergovernmental Panel on Climate Change; UNEP, United Nations Environment Program; UNCED, United Nations Conference on Environment and development; CAM, Crassulacean acid metabolism; WUE, water use efficiency; CAFOs, Concentrated animal feeding operations; SOC, Soil Organic Carbon; EPA, Environmental Protection Agency; LAI, leaf area index; EIA, Energy Information Administration;

Core Ideas

Causes
• The food industry is contributing 26% of anthropogenic GHG emissions
• Increase in secondary aerosols such as sulfate and nitrates post-industrial revolution
• Increased manure production due to an increase in concentrated animal feeding operations
• Inefficient nitrogenous fertilizers use on agricultural soils contribute 3.5 Tg N2O per year
• Deforestation accounts for 60-90% of net C emissions
• Carbon emissions of 13.34 and 9.39 Mg ha\(^{-1}\) from conventional and no-till, respectively.

**Effects**

• 24% atmospheric increase in CO\(_2\) concentration in the last 62 years
• Increased wildfire incidences
• Acidification of agricultural soil and oceans
• Increase in atmospheric gases could improve agriculture productivity, especially C3 plants

**Solutions**

• Eating a vegetarian diet
• Monitoring growing period weather carefully to address wildfire issues
• Adoption of no-tillage
• Lime application to acidic soils and ocean
• Halting deforestation and implementing reforestation
• Improving nitrogenous fertilizers use efficiency
Wildfires

From 1800 to 1900, the earth’s surface temperature increased by almost 2°F (NASA, 2020). Although a two-degree increase seems small and insignificant, its significance lies in the overall accumulated surface heat. This additional heat has influenced seasonal temperatures, and rainfall, causing an increase in the wildfire occurrence.

Climate change, by definition, is a change in global or regional climate patterns. While global change analyzes the earth as a whole, local variations are a more centralized focus for distinct areas of earth, continents, and states. The national aeronautical and space administration (NASA) recorded the effects of climate change and noted a temperature/heatwave increase, changes in precipitation patterns, and increased events of drought. Each of these global and regional changes has been shown to impact wildfire activity (NASA, 2020).

While in some areas, wildfires cause mass destruction; alternatively, they are essential to “fire-dependent” ecosystems. These fire-dependent ecosystems have evolved to withstand fire spread (Liu et al., 2010). These ecosystems include many coniferous boreal, temperate, and tropical forests, Mediterranean climates, some oak-dominated forests, and grasslands (Liu et al., 2010). Adjacent to these ecosystems is fire-influenced systems. These fire-influenced areas are known as “fire-sensitive” ecosystems. These ecosystems have evolved without fire as a significant process, but human activity has made them more vulnerable by altering plant life within, changing fuels, and increasing ignitions (Liu et al., 2010). Although fire has its complex role in ecosystems, the abundance of these wildfire occurrences has severe consequences.

Fluctuations in temperature affect seasonal weather periods, either shortening or extending them. Areas such as the Rocky Mountains have been experiencing earlier springs than usual, thus starting a rapid spring thaw and melting of surrounding ice. Furthermore, this has resulted in an increase in wildfire frequency in the Northern Rocky Mountains significantly (Scholze et al., 2006). Since the mid-1980s, the United States has experienced an increase in spring and summer temperatures, causing an increase in the number of western forest fires (Westerling et al., 2006). As a result of climate change effects on seasonal weather, creating longer summers and shorter winters, wildfire season length has increased by 78 days (Running, 2006). Since 2017, the earth’s global surface temperature has risen by 0.9°C compared to the average temperature in the mid-1900’s (Rossiello and Szema, 2019). Heatwaves are another concern as temperature increases; this accelerates drying of an area creating a perfect environment for ignition. During
July and August, wildfire activity for the western half of the United States increased (Westerling et al., 2003). These months are considered the driest and hottest months of the year as temperatures/heatwaves are known to reach triple digits, increasing the rate at which fuel is dried for ignition and expansion of fires. With these changes in climate, more areas ill-prepared for drought have begun to experience such events. The paleo record and historical data showed that changes in wildfire frequency are closely linked to changes in climate (Fried et al., 2004). Meteorological data and drought indices have been utilized to measure this relationship between climate change and wildfire activity (Dimitrakopoulos et al., 2011).

Why do events of prolonged drought have such an increase in wildfire activity? The drought does not cause the fire to occur during regular seasonal events. However, during a drought, both living and nonliving fuels can become dried out and more flammable (Littell et al., 2016). Plants become fuel through a process known as evapotranspiration. During this process, water within the plant's tissues evaporates outward into the atmosphere, leaving them wilted and dry. As the drought period continues, more of these fuels (Plants) become increasingly flammable, which helps with the ignition and spread of these wildfires.

Climate change through the course of El Nino and La Nina has the potential to impact precipitation events and intensity. Thus, causing an irregular average yearly rainfall regionally and globally. An environment's moisture availability drives the primary risk of wildfires (Westerling and Bryant, 2008). As for the months leading up to the wildfire season, it is important to observe the amount of precipitation and rainfall received closely. Having a wet growing season promotes the growth of the surrounding ecosystem vegetation. Changes in rainfall affect types of vegetation grown along with its growth potential. Such change can cause a shift in structure and composition, ultimately affecting moisture and combustion properties, altering an area's fire potential (Ryan, 1991). The growth of surrounding vegetation increases fuel accumulations for ignition. In south Florida, a study was conducted to show the relationship of wet season rainfall to the occurrence of wildfires. In this study, it was shown at the onset of the wet season; the most massive wildfires began (Slocum et al., 2010). As the climate changes, its effects spread to influencing plant processes such as photosynthesis, respiration, and organic matter decomposition (Scholze et al., 2006). As our environment is becoming warmer, the growth in fire-prone areas has slowly altered into highly flammable vegetation, which in turn increases the frequency of wildfires around the globe.

Several factors contribute to climate change and its impact on the increasing occurrence of wildfires. To answer the first question, has the occurrence of wildfires increased, or rather has it been the media’s ability to broadcast? Although there have been several advancements in media broadcasting technology, wildfire frequency has not fallen victim to over broadcasting. The number of wildfires has increased due to our global climate becoming increasingly warm (Westerling et al., 2006). This increase in temperature has influenced weather patterns, including
the frequency and severity of storms that produce lighting, one of the main causes of the start of wildfires. Regions similar to the western United States experienced extreme temperature, moisture, and storm fluctuations are quickly becoming wildfire breeding grounds and aid in the spreading of fires due to the buildup of excess vegetation.

**Aerosols**

Aerosols are a suspension of liquid, solid, or mixed particles in the atmosphere varying in composition and size (Myhre et al., 2013). There are two categories of Aerosols, primary, which are directly emitted into the atmosphere and secondary, formed from precursor gases. Aerosols can be inorganic or organic and enter into the atmosphere through natural or anthropological processes. Aerosols affect Earth’s global climate as they can either scatter or absorb solar energy, known as the direct radiative effect (Wilcox, 2010). Those that scatter sunlight do so by processes of reflection, refraction, or diffraction, and are known to cause a cooling effect to the Earth’s atmosphere through shortwave radiation (Boucher et al., 2013). The principal factors that determine the ability of a particle to reflect sunlight are the particle’s refractive index and size (Pope et al., 2012). Longwave radiation is responsible for the warming effects due to absorbing aerosols (Boucher et al., 2013). Direct radiative forcing is a climate-measuring tool that calculates the change in the direct radiative effect (Heald et al., 2014) and can be impacted through the size and composition of aerosols and their ability to impact cloud formation (Ramanathan and Xu, 2010; Wilcox, 2010). The amount of sunlight that is scattered or absorbed is measured by the optical depth, which denotes how much direct sunlight is prevented from reaching the ground. In cloud formation processes, aerosols are the foundation of cloud condensation nuclei and ice nuclei that could affect precipitation and evaporation, causing a warming or cooling effect. This process is generally either called a semi-direct or indirect effect, depending on what climatic factors are present (Rosenfeld et al., 2014).

Aerosol composition dictates their atmospheric impact. An example of this is the variance within the Asian continent that was observed by Lau et al. (2010). The authors found a 1-2°C temperature anomaly within the region that could be attributed to different aerosol composition. The Indian continent had a 57% absorbing aerosol, while East Asia was found to be dominated by sulfates (62%). Volcanic ash, sea spray, and mineral dust are all examples of primary aerosols that enter into the environment through natural processes. Volcanic ash is suspended into the atmosphere following a volcanic eruption and can stay in the atmosphere for up to two years (NASA, 1996). Volcanic ash is an example of reflecting aerosol, because it scatters the solar radiation, causing global cooling effects. Soden et al. (2002) observed a global mean tropospheric cooling of 0.3°C after the 1991 eruption of Mount Pinatubo in the Philippines. This cooling effect can be attributed to sulfur dioxide (SO₂) injected by volcanic plumes into the
stratosphere where it oxidizes and reflects incoming solar energy away from Earth’s surface (Solomon et al., 2011). Seasepray is composed of sea salt and marine organic matter. It enters into the atmosphere by water bubbles bursting due to breaking waves (Boucher et al., 2013) with an emission rate estimated to be 2-20 Tg yr\(^{-1}\) (Gantt et al., 2011). Mineral dust is an example of an absorbing aerosol and is typically found over the Atlantic Ocean in the form of desert dust veils (NASA, 1996). Black carbon is a primary absorbing aerosol that warms the atmosphere where it is suspended and is significant to global warming (Koch and Del Genio, 2010). It can enter into the atmosphere through anthropological processes, including the combustion of fossil fuels, biofuels, and biomass (Boucher et al., 2013).

Secondary aerosols are produced in the atmosphere from precursor gases through the condensation of vapors on pre-existing particles or by nucleation of new particles. They are a mixture of sulfate, nitrate, and organic carbon (Myhre et al., 2013). The rise in concentrations of secondary aerosols in the atmosphere is associated with the Industrial Revolution in 1750 (Boucher et al., 2013), and due to technology limitations, pre-industrial levels of these aerosols are generally underestimated (Ramanathan and Xu, 2010). The SO\(_2\) that contributes to the global cooling effect from the Mount Pinatubo eruption is considered a secondary aerosol. Since the Industrial Revolution, it is believed that sulfate-based aerosols outnumbered naturally made aerosols in the atmosphere (NASA, 1996). Another secondary aerosol that can be emitted from natural or anthropological sources is nitrates. Nitrates are formed from the oxidation of nitric oxide (NO\(_x\)) and are considered a reflective aerosol, causing a cooling effect (Ramanathan and Xu, 2010).

The cloud albedo effect describes how solar radiation is impacted by cloud formation (Twomey, 1977). Absorbing aerosols can modify cloud properties by heating the air surrounding them while reducing the amount of solar radiation reaching the ground, which in turn can limit cloud formation. The lack of cloud formation will increase the atmospheric temperature, which can enhance the evaporation of existing clouds (Myhre et al., 2013). When the absorbing aerosol mixes with shallow broken clouds in the same atmospheric layer, the radiative heating of the layer by solar absorption can reduce the cloud cover, thus increasing the absorption of solar radiation at the surface and leading to a net positive radiative forcing (Wilcox, 2010). A detailed sample of stratocumulus cloud yielded the results with individual particle compositions that varied and increased fresh and processed sea salt particles, biomass-burning particles, sulfates mixed with organics, and a large number of organic particles (McFarquhar et al., 2011).

Aerosols provide the foundation for cloud condensation nuclei and ice nuclei, which form cloud droplets and ice particles. The introduction of cloud condensation nuclei can lead to an increased number of smaller cloud droplets that will increase the albedo of the cloud resulting in a cooling effect (Li et al., 2011; Myhre et al., 2013). An increase in absorbing aerosols allows for the increased rate of absorption that can cause dissipation of the cloud layer. McFarquhar et al.
(2011) found a highly significant relationship between the number of droplets and aerosol concentration levels. Mixed-phase clouds (generally found at the temperature range of 0°C to -38°C) have a significant impact on the radiative budget and occur in both single and multiple layers with a typical layer structure having liquid tops and precipitating ice (McFarquhar et al., 2011). Aerosols can cause cloud formations to be sensitive to the phase changes from ice to liquid. Mineral dust and volcanic ash are considered to be good ice nuclei (Boucher et al., 2013), while black carbon can act as both cloud condensation and ice nuclei (Koch and Del Genio, 2010).

Evidence that aerosols can scatter solar radiation, causing a cooling effect has led to the idea of purposely injecting aerosols into the atmosphere to combat global warming (Pope et al., 2012). The unpredictability of aerosol behavior in certain atmospheric conditions adds caution to the practice. The main concern of direct injection is the effect on the ozone layer (Boucher et al., 2013; Pope et al., 2012). The depletion of the ozone layer will increase the amount of ultraviolet radiation reaching the Earth’s surface, which can negatively affect the ecosystem (Boucher et al., 2013). Increased incidences of acid rain, increased rates of photosynthesis, and an increase in ocean acidification, all factor into the unpredictable outcome of direct injection. If implemented, another issue that can arise from the practice is the rapid warming that will occur when direct injections cease.

**Animal Industry**

Greenhouse gasses (GHG) are gases that absorb and emit infrared radiation, letting the sun’s radiation into the atmosphere while retaining its heat. The gasses attributed to these characteristics are in order of abundance: Water vapor (H\textsubscript{2}O), carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), nitrous oxide (N\textsubscript{2}O), ozone (O\textsubscript{3}), chlorofluorocarbons (CFC’s), and hydrofluorocarbons (HFC’s).

These gasses are contributed by many sources; animal production is a significant source of CO\textsubscript{2} and CH\textsubscript{4} pollution in the world. The current food industry produces approximately 13.7 billion metric tons of CO\textsubscript{2}, contributing 26% of anthropogenic GHG emissions (Poore and Nemeck, 2018). Animals and specifically ruminants produce CO\textsubscript{2} and CH\textsubscript{4}, but the problem is not the animals themselves but vast numbers consumed by humans. Approximately 56 billion animals are raised and slaughtered for human consumption every year (FAOSTAT, 2008). Livestock numbers are predicted to double by the year 2050, mostly in developing countries, subsequently increasing their food requirement (Koneswaran and Nierenberg, 2008).

Currently, around the world, there are about 23 billion chickens, 1.5 billion cattle, 1 billion sheep, and 1 billion pigs (FAO, 2017). All of these animals need to be fed to produce the meat required for human consumption. When it comes to land use and management, 83% of all the
worlds’ farmlands are used for feed production for the animals, pasture, or fodder crops such as hay, straw, silage, and legumes (Poore and Nemeck, 2018). Including irrigation, meat, and dairy production accounts for 27% of worldwide freshwater consumption (Hoekstra and Mekonnen, 2012). Freshwater and fertile land are indirect factors of global climate change; both valuable resources inefficiently used nonetheless. The current meat production sector is extremely inefficient polluting resources, such as water, land, and fossil fuels.Livestock is living animals, and they spend most of their energy gained from the fodder crops and pastures to live while gaining the desired weight needed before slaughter. Only a fraction of the nutrients obtained from the fodder crops ends up into the consumable meat, 4% of the proteins, and 3% of the total calories. Meaning approximately 97% of the calories used to raise the cattle are lost (Shepon et al., 2016). For one kg of steak production, a cow needs around 25 kg of grain and 15,000 liters of freshwater (Hoekstra and Mekonnen, 2012). Animal products in our modern world use tons of food, yet only makes up 18% of the total human caloric intake. Certain projections noted that we could nourish an additional 3.5 billion people if we simply ate crops fed to animals (Cassidy et al., 2013). To make our global resource problem worse, all of the farmland used to feed these animals is land that has been deforested for agricultural use and forests that previously sequestered carbon.

Beef and milk production are the largest contributors to CH₄ pollution. About 15% of all greenhouse emissions caused by human activity are coming from the meat industry. This is equivalent to the entire transport industry, trains, cars, ships, and planes combined (Poore and Nemecek, 2018). Methane itself is the most abundant organic gas in the atmosphere; evidence has proven that the concentrations of CH₄ in earth’s atmosphere has steadily increased over time approximately 0.7% or 12 Parts per Billion (ppb) per year in the ten years since 1994 (Harper et al., 1999). Today's CH₄ concentrations are about 1.8 ppm in the earth’s atmosphere. Methane pollution comes from many sources, but as previously stated, a large portion of CH₄ production comes from cattle directly. Out of the 70% of CH₄ produced from anthropogenic sources, agriculture is responsible for about two-thirds. Ruminant animals such as cattle, sheep, and goats all complete the digestive process of enteric fermentation. This digestive process uses microorganisms in a symbiotic relationship with the ruminant animal to break down the carbohydrates from the forage feeds into simple molecules, used for absorption into the animal’s bloodstream; this process produces CH₄ gas as a byproduct. Total ruminant enteric fermentation produces 80 million MT of CH₄ per year. This, coupled with the animal waste fermentation of 25 MT of CH₄ per year, accumulates to a total of 105 MT of methane per year, or about half of all agricultural CH₄ production (Moss et al., 2000).

One major way to combat the pollution caused by the agricultural industry is an alteration in the human diet (Popp et al., 2010). In certain countries like the United States of America, it is a cultural norm to have meat with almost every meal of the day, with beef being a large portion of
that diet. With a slight change to eating less meat in the day or the week or from switching from beef and mutton to fish or chicken, CH$_4$ and CO$_2$ pollution could be decreased (Thorpe, 2009). As more people across the globe change to vegetarian or even vegan diets, greenhouse gas emissions can be reduced. The grains we consume result in less environmental impact compared to the meat and animal industry. With the correct knowledge, all macro and micronutrients could be obtained from a strictly plant-based diet. Still, the challenge of changing the world’s population to a heavy plant diet is not physiological, but a cultural one (Jasanoff et al., 1998).

**Policy/Politics**

On June 23, 1988, the world of politics in the United States changed forever. On this day, Dr. James Hansen of the NASA Goddard Institute for Space Studies testified to congress presenting evidence that the climate was changing. Dr. Hansen’s testimony, along with the 1988 heatwave and other weather anomalies, influenced both research and political activism about climate change (Demeritt, 2001). Other noteworthy events, such as the 1979 World Climate Conference or the establishment of the Advisory Group on Greenhouse Gases in 1985, played a pivotal role in climate change politics (Gupta, 2010).

Dr. Hansen’s testimony to the U.S. Congress in 1988 opened the door for expanded research and extension in climate change. Quickly conferences were arranged to assess the state of knowledge on global warming (Paterson, 1996). This testimony led to the creation of the Intergovernmental Panel on Climate Change (IPCC) by the United Nations Environment Program (UNEP) and the World Meteorological Organization later in the same year (Gupta, 2010). As these programs and organizations were building public support, political action on all sides of the debate became fluid in industrialized nations. The increase in support for political action to alter the current climate change path was apparent globally as nations signed the ‘Framework Convention on Climate Change’ at the United Nations Conference on Environment and Development (UNCED) in June 1992 in Rio de Janeiro (Paterson, 1996). The framework set in Rio de Janeiro further led to the debate on climate change. These debates have been at the forefront of not only global politics when considering action regarding treaties and agreements between nations, but also on the political landscape of America.

Environmental issues became more intertwined with politics in the U.S. in the late 80’s early ’90s and increased questioning by opponents of new policy initiatives and treaties such as the Kyoto Protocol in 1997 (McCright and Dunlap, 2011) from which the U.S. withdrew itself in 2001 (Gupta, 2010). As the U.S. entered into the 21st century, terrorist attacks on 9/11 and the subsequent war on terror moved environmental issues to the backburner of the Bush administration’s political agenda (McCright and Shwom, 2010).
As far as recent major policy initiatives go, the 2015 Paris Agreement pledged to keep average global temperatures well below 1.5-2.0°C above pre-industrial levels and was agreed upon by over 190 nations. The Obama administration largely drove this global agreement along with other UN nations such as China and the EU (Tollefson, 2017). However, in June 2017, President Donald Trump withdrew from the Paris Agreement. This was not unprecedented for the U.S., as George W. Bush had previously withdrawn the U.S. from the Kyoto Protocol in 2001 (Tollefson, 2017).

Today, the U.S. political landscape makes it extremely hard to construct lasting and meaningful national environmental policy initiatives, let alone joining and remaining a part of global ones. While efforts have been made to put together some sort of domestic climate policy initiatives such as the McCain Lieberman proposal at the 109th session of the U.S. Senate and the Waxman Markey bill of 2010 (Kemp, 2017). The current state of U.S. climate policy has largely been an intensely divided issue with a split along party lines (Guber and Bosso, 2009). This division has led to gridlock in Congress regarding climate change, with the only progress being the use of Presidential Executive Orders (Kemp, 2017). The Obama administration agreed to be part of the Paris agreement using the power of the executive to avoid the obstacle of obtaining a necessary supermajority in the U.S. Senate (Kemp, 2017). The Trump administration also used the Presidential Executive order to withdraw from the agreement in 2017.

Numerous papers have addressed the relationship between public perception and ideology on climate change and the alignment of political ideology and party identification. One noted that Americans believe that global warming is influenced by both political ideology and political party identification (McCright and Dunlap 2011). While it is clear that the politicization of climate change and other environmental issues has come as a detriment to progress in the U.S., it is also worth noting that overall public concern for environmental issues such as global warming and pollution has not only leveled off but also even deteriorated to an extent. According to Guber (2013), public concern for global warming declined between 2007 and 2010 along with public concern for pollution of rivers, lakes and reservoirs, and air pollution. This decline could be hypothesized to have been a reaction to greater public concern in response to the Great Recession of late 2000, which is similar to that of the decline after the terrorist attacks on September 11, 2011 (Guber, 2013).

There are many parameters discussed in publications over the last decade, attempting to define the drivers of the politicization of global warming and other environmental concerns. Parameters such as education and religious belief, income, race, and others may drive political alignment and, thus, to some degree of ideology over environmental and climate-related issues. However, as much as researchers tried to understand why there is separation, it appears that there will be division on controversial issues such a climate and environmental policy for the near future. This division shows that as far as meaningful progress goes in the U.S. in regards to both domestic
and global climate and environmental policy, there is much work to be done (IPCC, 2007; Rosenthal and Revkin, 2007).

While today the politics and policy of the environment and climate are greatly intertwined, there have been several attempts to overcome these obstacles through the development of policy initiatives that feed into both conservative and liberal political ideologies (Hovi et al., 2009). Policies such as emissions pricing schemes like the cap and trade system that could potentially develop new markets that put a focus on research and development of new technologies that reduce emissions. Some activists and policymakers (Doran and Ginochio, 2007) may favor other policy ideas such as an emission tax that creates a disincentive for pollution through the emission of GHG. Regardless of policy put forth, in the future, there will have to be meaningful collaboration across party lines involving groups that would be deemed to have “skin in the game” including but not limited to agriculture, oil and gas, manufacturing, coal and the alternative energy industries to name a few. Seemingly without involving all sides of the issue, no progress on climate and environmental policy will likely be made soon leaving the U.S. open to criticism in the global political arena and undeniably the second largest producer of greenhouse gas emissions (Gupta, 2010) without meaningful progress towards a solution to global warming.

**Positive Effects via Elevated Carbon Dioxide**

Greenhouse gases have altered and will continue to alter atmospheric gas levels. One of GHGs that has been the cause of concern is CO$_2$, and atmospheric CO$_2$ levels are expected to double in the 21st century (Bowes, 1993). This, in part, is due to increased soil tillage, resulting in CO$_2$ emissions from decomposing soil organic matter (Schlesinger, 1984; Mullen et al., 1999). Increasing CO$_2$ levels are detrimental to the environment, and it has risen substantially from pre-industrial levels (Kirschbaum, 1994).

Plants are dependent on the environment for adequate levels of light, temperature, nutrients, and water for survival. Agriculture, as a large plant producing community, could potentially benefit or at least utilize the increasing amount of atmospheric C, as current concentrations limit photosynthesis to about sixty to seventy percent of its potential (Bowes, 1993). Carbon is needed in all plants, like the Calvin cycle demands C fixation for plant growth (Dahlman et al., 1985; Drake and Leadley, 1991). Plants that are C4 and Crassulacean acid metabolism (CAM) are significantly more efficient in C fixation, as they do not participate in photorespiration. This means that Calvin cycles in C4 and CAM plants are more efficient in the C fixation, as PEP
carboxylase is used, which is not prone to fixing oxygen and wasting plants' energy (Bowes, 1993). With the increase of atmospheric carbon, C3 plants can increase their efficiency in C fixation. This increase in carbon fixation could create large gains in plant production as ninety-five percent of terrestrial plants are C3, one percent is C4, and the remaining four percent are CAM plants (Bowes, 1993).

While there are many concerns associated with increased CO$_2$, this increase in atmospheric gases could lead to an increase in agricultural productivity (Warrick, 1988). One process that can be targeted for increased efficiency is photosynthesis, specifically in C3 plants. Rubisco is the enzyme responsible for carbon fixation. In C3 plants, Rubisco can also fix oxygen, creating a competition between CO$_2$ and oxygen. With the increase in atmospheric CO$_2$, a greater concentration of CO$_2$ gives C3 plants an advantage for fixing C, rather than oxygen, during photosynthesis (Badger, 1992).

As improvement in photosynthesis efficiency occurs, it suggests that other plant production factors will be impacted. Increased CO$_2$ levels are involved in increases of several productivity measurements. Studies have found higher CO$_2$ levels to increase biomass production, root-to-shoot ratios, greater leaf area, leaf area index (LAI), leaf area duration, and leaf thickness (Bowes, 1993; Tyree and Alexander, 1993). Increased numbers of branches, tillers, stem and root length, fruit size, and numbers of flowers, fruits, and seeds are associated with higher CO$_2$ levels (Bowes, 1993).

Increases in C fixation and photosynthesis efficiency suggests that light, nitrogen (N), and water use efficiency (WUE) will also increase (Drake et al., 1997; Tyree and Alexander, 1993). For environments with higher CO$_2$, plant-water relations have been found to adapt to the surrounding conditions. Elevated atmospheric CO$_2$ has been found to decrease transpiration, indicating that it may lead to increased WUE. In studies of increased CO$_2$ environments, plants maintained water when compared to control groups of normal CO$_2$ levels that had been depleted (Bottomley et al., 1993; Drake et al., 1997). In limited water conditions, C3 plants, wheat, and cotton have been found to benefit from increased CO$_2$, more so than C4 plants (Kang et al., 2002). While many of these results have been achieved through constant exposure to high CO$_2$, increases have also been found in studies evaluating limited daily intervals. Higher CO$_2$ levels at intervals throughout the day have also shown increased production in several species (Ziska et al., 2001). As CO$_2$ levels can vary from season to season throughout the year, these results indicate that even limited exposure to increased levels of CO$_2$ can influence productivity.

It is thought that increased CO$_2$ levels change C:N uptake ratios, which would limit amounts of plant N. However, it was found that plants could alter root and shoot growth to meet the plant’s nutrient needs (Ishizaki et al., 2003). Production levels are highest under elevated CO$_2$ when higher levels of N are available (Ishizaki et al., 2003). It is important to recognize that while
these results occurred in elevated CO₂ conditions, they might not occur if these plants were under nutrient stress. Alternatively, it has been found that no additional N was needed in high CO₂ conditions for mixed-species communities (Jackson and Reynolds, 1996).

**Impact of Lime**

Agriculture has released one-third of the total GHG emissions, including CO₂ (Gilbert, 2012). Agriculture is also responsible for mitigating global warming, and several studies are underway to reduce the sources or enhance the sinks that accumulate and store the GHGs (Cole et al., 1997; Smith et al., 2008; Singh et al., 2019). As a method to decrease global warming, no-tillage management has been promoted, and fertilizer inputs have been readjusted following changes considered for crop residues (Sims et al., 1998; Six et al., 2004; Bernacchi et al., 2005; Reay et al., 2008; Wortmann et al., 2016).

Agricultural lime is another way for global warming mitigation in agriculture fields. Approximately 50% of the world’s potentially arable soils have soil acidity problems, and it causes significant losses in biomass that restricts the ability to sequester C, as well as crop production (Kochian et al., 2004). To counteract soil acidity, lime provides nutrients like calcium (Ca) and magnesium (Mg). It improves the uptake of major plant nutrients like N, phosphorus (P), and potassium (K) (Hamilton et al., 2007). It can increase the capacity of soil organic carbon (SOC) sinks, including CO₂ (Paradelo et al., 2015). Liming can also reduce the use of N fertilizer, which is a key cause of increased GHG emission (Fornara et al., 2011). Hamilton et al. (2007) showed 1.9 Tg yr⁻¹ of CO₂ could be sequestered in the soil with an application of 30 Tg yr⁻¹ of agricultural lime. Several previous studies argued that agricultural lime releases CO₂ when it reacts with strong acidic sources such as nitric acid (HNO₃) (Biasi et al., 2008). West and McBride (2005) anticipated that when 20-30 Tg yr⁻¹ of agricultural lime was applied, 4.4-6.6 Tg yr⁻¹ of CO₂ emissions would have occurred. However, the long-term effects of liming on SOC sequestration are largely unknown; nevertheless, many previous works predicted it would be positive as a terrestrial C sink (West and McBride, 2005; Hamilton et al., 2007; Fornara et al., 2011; Paradelo et al., 2015).

Many researchers also noted that liming the ocean could affect oceanic C sinks (Harvey et al., 2008; Kruger, 2010; Hartmann et al., 2013; Renforth and Henderson, 2017). Ocean acidification affects ocean species as it decreases the abundance of calcium carbonate, posing a threat to marine ecosystems (NOAA, 2020). Gruber et al. (2019) showed the ocean sink estimate is consistent with expectations of the ocean uptake has increased in proportion to rising in atmospheric CO₂, but warned that ocean sinks for CO₂ could be reduced due to marine ecosystem changes. Harvey et al. (2008) supported liming to increase the absorption of atmospheric CO₂ as relieving ocean acidification. Hartmann et al. (2013) also found liming to remove CO₂ and dissolve CO₂ to bicarbonate that increases alkalinity and pH of natural waters,
even though the extent remains difficult to quantify. Renforth and Henderson (2017) showed dissolving lime in seawater leads to uptake of CO$_2$ from the atmosphere. However, the effect of lime on oceans should be evaluated as a long-term perspective that requires at least 50 years, not a short-term change (Harvey et al., 2008; Renforth and Henderson, 2017).

Liming effects should be key to global warming mitigation. In the short term, it can be considered to release CO$_2$, deepening global warming. However, to counteract acidity, neutralizing soil and ocean sinks can improve production. Both terrestrial and oceanic C sinks also can expand their capacity of CO$_2$. Application of agricultural lime can be suggested as expanding terrestrial, and ocean C sinks in the long run and counteracting soil or ocean acidity for global warming mitigation (West and McBride, 2005; Harvey et al., 2008; Renforth and Henderson, 2017).

Henderson et al. (2008) showed when 40.8 GT of limestone added to the ocean, and it would raise surface ocean alkalinity by 1.95% per year that is sufficient to absorb the 3.41 GT C including the additional CO$_2$ released when lime dissolved. The lime effect can be offset or be more beneficial to C sinks on earth when it is applied to land and ocean for solving the acidity problem. Land plants and the ocean can absorb at least 24% of total C in the atmosphere as well as expanding terrestrial and ocean C sinks, lime can balance these ecosystems as counteracting soil or ocean acidity. In the end, a balanced ecosystem will be stable and increase the capacity of C sink even though that effect is difficult to quantify.

Environmental Impact of Concentrated Animal Feeding Operations

Concentrated animal feeding operations (CAFOs) are an important part of livestock production in the agriculture industry focused on food production. Fewer operations and increasing sizes have been the trend over the past two decades for livestock production (Thorne, 2007). With these increases in operation size, and environmental impact is unavoidable. Over seven years, the number of concentrated animal feeding operations in the U.S. increased by 1,421 (Walljasper, 2018).

The increase in the concentration of CAFOs has led to excessive manure production, raising problems with management and storage, leading to air and water pollution. The largest environmental concern associated with CAFOs is the quality and quantity of manure produced (Hribar, 2010). This amounts to 2,800 to 1.6 million tons per year of manure, depending on the type and size of the operation (GAO, 2008). The larger farms' waste production is even greater than in some U.S. cities. Disposal of this amount of manure has become problematic, with ground spreading being the simplest and most cost-effective method. However, there are major
application limitations with this method, including quantity to be applied, and the inability of application on the frozen ground (Hribar, 2010).

Over application of manure can lead to nutrient overload in the soil (Burkholder et al., 2007). Over applications of nutrients, such as N, could lead to losses such as leaching and volatilization, influencing the environment. Most manure produced by CAFOs is applied to land, which leads to leaching, runoff, and can result in air emissions as well (Merkel, 2002). When manure is chemically breaking down during storage creates air pollutants and GHGs, which contribute towards global warming (Hribar, 2010).

Additionally, groundwater can become contaminated by CAFOs through many sources, including leaching of over-applied manure and leaks or breaks in storage and containment units. A study conducted in Idaho found nitrate levels, at or higher than 10 mg L⁻¹, in five of the six wells tested (Batt et al., 2006). This study also found evidence of veterinary antibiotics in detectable levels in all wells tested. The Environmental Protection Agency (EPA) reports 53% of the population relies on groundwater (EPA, 2004). When the lateral movement of water is considered, contaminated groundwater can also eventually enter surface waters, such as rivers or streams. This poses a major risk to the majority of the population utilizing groundwater as their sole water source.

Surface water is also another area of concern for pollution when considering the impact of CAFOs on the environment. One major method of storage of effluent, the liquid discharge of manure treatment, is a large lined pond where the liquid is collected and stored, called a lagoon. This is a potential hazard to the environment in cases where the lagoon wall was breached due to a leak or flooding (Spellman and Whiting, 2007). When this occurs, the lagoon liquid begins to leak on the surface and can run off into rivers and streams. States with high concentrations of CAFOs, on average, experience 20 to 30 water issues per year because of manure management (Browner, 2001). Accumulation in various sources of N resulting from contamination of surface water can cause nitrate build-up as well as deplete oxygen concentration in the water, resulting in reductions in aquatic life and eutrophication.

Similarly, CAFOs also contribute to the reduction in air quality for surrounding areas. Some effects of this are easy to identify with signs such as dust in the air and the smell of manure/effluent. Dust and suspended particles in the air from CAFOs can result in asthma symptoms, especially in children (Barrett, 2006). As compared to adults, children inhale 25 to 50 % more air, therefore making them more susceptible. The CAFOs emitted odors are a result of a mixture of ammonia hydrogen sulfide and CO₂, as well as other volatile organic compounds (Heederik et al., 2007). Other less obvious effects are gaseous emissions from the manure and effluent from the decomposition of manure and volatilization of effluent contents. Volatilization of NH₃ and the release of nitrogen gases (N₂O, NO, N₂) into the atmosphere can result from
improper land applications of manure. These gases are partially responsible for global warming. A study conducted in western Kentucky evaluated the ammonia emission of two chicken houses over a year. The two chicken houses evaluated were found to emit 4.5 and 5.7 Mgs of NH₃ per year per house resulting in 1.4 to 5.5 kg per bird per day (Burns et al., 2007). These emissions are only one example of the 19,961 CAFOs reported by Walljasper (2018).

Greenhouse gas emissions from CAFOs not only affect the air quality in surrounding areas, but they also harm the atmosphere. This includes 18% of the global GHG emissions that are a result of CAFOs, with 7% of the total contribution to U.S. GHG emissions. Eighty-six million metric tons (MMT) of CO₂ emissions were estimated in 2016 to be caused by manure management (Massey et al., 2008). Most GHG emissions are in the form of CH₄ and come from dairy and swine operations that rely heavily on liquid manure management systems. The GHG emission contribution of each type of CAFO is dairy cattle (48%), swine production (32%) beef cattle production (13%), and poultry (6%) (Massey et al., 2008). The Environmental Protection Agency reports manure management as the fourth largest contributor to CH₄ and N₂O emissions, with an increase of 30.5 MMT and 4.1 MMT, respectively, over 26 years (EPA, 2009).

Concentrated animal feeding operations have many potential areas of concern when considering environmentally influential factors. The manure management of CAFOs is often targeted as the major impacting factor, with the vast opportunities for mismanagement leading to environmental contamination. The potential exists for effluent containing lagoons to leach into groundwater, overflow into rivers or streams, and volatilize off into the atmosphere. With the increase of CAFOs and the increasing size of these operations, these concerns continue to grow and become more of a problem for future generations. Although CAFOs only make up 18% of all global GHG emissions (Massey et al., 2008), this is an area that will need to be improved to reduce emissions as the industry continues to grow.

**Nitrous Oxide Emissions from Nitrogen Fertilizers**

Nitrous oxide concentration in the atmosphere is influenced by human activity. The widespread use of chemical fertilizers in agriculture and the combustion of fossil fuels is recognized as the cause of the increase in N₂O concentration in the atmosphere. Nonetheless, the rise in the earth’s temperature is related to the increase of the N₂O level in the atmosphere (Wang et al., 1976). Crutzen (1970), in a short review, described the importance of N₂O considering ozone concentrations and production in the stratosphere. According to the IPCC (2006), N₂O has a higher impact than CO₂ on the global warming process, on a 100 years’ time scale. This report also states that agricultural soils contributed 3.5 Tg N₂O per year of a total of 5.7 Tg N₂O of the anthropogenic emissions.
Flückiger et al. (2002) reported that N$_2$O concentrations in the atmosphere were stable until the beginning of the industrial revolution. The author describes that the N$_2$O level in the atmosphere has increased from 270 ppb to the value of 331 ppb (18% increase). The higher concentration is credited mainly to agriculture. Nitrous Oxide emissions by natural reasons from land and oceans have been estimated at 11 Tg N$_2$O between 2006 and 2011. Considering that the total emissions are estimated at 17.9 Tg N$_2$O in the same period, anthropogenic influence within the N cycle is evident since 5.6 Tg N$_2$O of the total is due to agricultural activities (Ciais et al., 2014).

An increasing world population leads to an increased demand for fiber, food, and energy production. Agricultural growth has resulted in, on average, 1.10% per year N$_2$O emissions from 1961 to 2010. Considering the emissions from N fertilizers, the average rate increased by 3.9% per year (Aneja et al., 2019). Considering the N cycle, nitrification and denitrification are two pathways where N$_2$O is produced. Nitrification is the aerobic oxidation of NH$_3$ or NH$_4^+$ to NO$_2^-$ followed by the oxidation to NO$_3^-$. In this process, bacteria in the soils produce N$_2$O that is lost to the soil environment and later exposed to the atmosphere. Denitrification is the process in which NO$_2^-$ and NO$_3^-$ are reduced in the soil by microbial activity, and a portion is converted to N$_2$O (Butterbach-Bahl et al., 2013). These two processes are critical to understanding the N$_2$O emission, and they are influenced by physical, chemical, and biological factors and their interaction.

Kim et al. (2013) addressed the linear or nonlinear relation of N$_2$O emissions caused by N fertilizer input in production systems. The datasets utilized in this review had at least four levels of N. The authors found that the nonlinear response between the N$_2$O emissions and the nitrogen rate applied was more frequent (18 of the 26). An essential contribution of this article is the emission factors utilized where global reports are only approximations since the emission factors change with the increase of the N fertilizer input in production system soils. One apparent problem of the study was that the authors only utilized studies from North America (the USA and Canada) and Europe that means that the evaluation did not cover high potential emission areas in Asia and South America.

Similarly, Aneja et al. (2019) utilized several datasets. They found that global models, such as the Emission Database for Global Atmospheric Research (EDGAR) and Food and Agriculture Organization of the United Nations (FAOSTAT), were estimating the emissions differently. Aneja et al. (2019) estimated 9 to 20% lower emissions than the EDGAR and FAOSTAT models, respectively.

**Deforestation**
Carbon is considered a product of the transfer of energy between the biosphere and atmosphere, assimilated by photosynthesis, and released to the atmosphere through autotrophic and heterotrophic respiration, with tropical rainforests exuding the highest C contributions (Malhi et al., 1998). The surface of the planet is composed of 12% of such rainforests that are a critical component of regulating and retaining nearly half of the terrestrial gross C productivity (Whittaker and Likens, 1975). Taking both tropical forests and woody savannas into account, nearly 50% of the global forest area and 60% of global terrestrial photosynthesis are accounted for (Malhi and Grace, 2000). It has been stated that the majority of C released from forests and soils are traced back to the tropics (Detwiller, 1986). Across Amazonia, spatial stability in the diurnal C cycle has been noted as a reflection of inputs and control factors of gross photosynthesis, plant respiration, and eventual release of C to the atmosphere, aided by decomposition and respiration through microbes and heterotrophs (Malhi and Grace, 2000). Yet, spatial uniformity in bulk Ecophysiological characteristics are retained (Malhi et al., 1998). These plant regulatory processes play a key role in balancing C acquisition and release. Equilibrium of this cycle is sensitive to shifts in magnitude that, in turn, influence the global C cycle (Malhi et al., 1999). The cycle of C follows the release into the atmosphere when forestland is cleared, while regrowth following disturbance sequesters C from the atmosphere and returns it to be stored within the plant body and soil (Houghton et al., 1991). Forest clearing and plant biomass degradation are significant sources of atmospheric CO₂ content and as a C sink, estimated to emit 3.0 Pg C year⁻¹ (Malhi and Grace, 2000).

The three primary tropical forest zones are found in South America, Central Africa, and Southeast Asia, all of which are experiencing rapid deforestation, with tropical Asia to the highest (Malhi and Grace, 2000; Palm et al., 1986). The largest drivers of clearing tropical forests are permanent or shifting cropland production, cattle range, and logging enterprises, contributing to 55%, 12%, 20%, and 12% of losses, respectively (Malhi and Grace, 2000). The conversion of tropical forests to cropland is the largest contributor releasing large amounts of C into the atmosphere due to forest conversion and changes in the biosphere (Houghton, 2012; Geist and Lambin, 2001). Not only has the biosphere been affected by these practices, but also it is altered with the chance of no reconciliation or reestablishment (Nobre et al., 1991). The rapid destruction of tropical forests in Amazonia has disrupted the environment’s hydrological cycle by reductions in regional evapotranspiration, moisture flux, and changed native and complex plant-animal dependencies (Nobre et al., 1991).

Deforestation must be considered when evaluating the global C budget as it accounts for 60-90% of net C emissions, estimated at an average of 1.4 Pg C year⁻¹ from 1990 to 2009 (Houghton, 2012). In some areas, this average C emission has been estimated to decline, while being offset by rises in others, leaving uncertainty in the rates of land-use change (Houghton, 2012). It has been stated that actual forest biomass and post-disturbance losses from soil C per unit area are
lower than the past and previous claims (Palm et al., 1986; Houghton et al., 1987; Achard et al., 2002). Regardless, biotic emissions are still shown to have neared or possibly exceeded the rate of growth of fossil fuel emissions in the global C budget (Houghton et al., 1991; Detwiller, 1986).

When evaluating solutions, halting deforestation, and implementing reforestation alone could return as much as 3 Pg of C annually from the atmosphere and reduce current C emissions by 2 to 3 Pg (Houghton, 1990). However, it must be taken into account that re-populated trees actively sequester C while growing and are ambient in C regulatory aid once mature (Houghton, 1990).

**Tillage Management for CO₂ Emission Reduction**

According to the website information developed by the Earth Science Communications Team (2020), the global atmospheric CO₂ level has reached 412 parts per million (ppm) as of December 2019. The primary reason for this significant rise in CO₂ is the contribution of anthropogenic or human activities over the past few decades.

Several of our agricultural activities could result in the production of CO₂ gas but could also be a potential strategy for sequestering CO₂ from the atmosphere. According to Smith et al. (2008), agricultural lands have the potential to sequester approximately 5500-6000 Mg CO₂-eq. yr⁻¹ by 2030. This is possible in crop production, where we can develop farming strategies that could result in sequestration of C into our soils. This could offset the production of greenhouse gases brought by other human activities (Lenka and Lal, 2013).

Tillage is known to have several advantages and disadvantages in terms of its direct and indirect effects on soil physical, chemical, and biological properties. The primary importance of tillage is to loosen the soil and control weeds for better crop performance. A study by Kavalaris and Gemtos (1998) under low biomass cotton crop production have shown that conventional tillage gave the best yield at 4 Mg ha⁻¹ compared to 3.8 Mg ha⁻¹, 3.2 Mg ha⁻¹; and 2.8 Mg ha⁻¹ when using heavy cultivator, a rotary cultivator with disc harrow, and no-tillage, respectively. Contrasting results were reported by Bono et al. (2008) and showed much higher yield and biomass in rotational crops grown under no-till systems compared to the conventional tillage system. They attributed this to the higher soil moisture content in the no-till system under semiarid environmental conditions. Because of this, C input to the soil was higher in the no-till system than in a conventional system. Organic C in the soil was found to be 5.4 Mg ha⁻¹ higher under no-till than in the conventional disk tillage after six years. Omara et al. (2019) noted no-tillage as a sustainable long-term strategy for improving soil quality and crop productivity. Nonetheless, more studies have noted that conventional tillage yields more than the no-till system. This is probably under conditions or environments where soil moisture and rainfall are
not limiting. Other reasons were pointed out, such that in no-till systems, soils tend to have higher bulk density, shear strength, and resistance to penetration (Kavalaris and Gemtos, 1998) that delays the emergence of plants such as cotton. While for corn production, the low yield obtained in a no-till system was attributed to cooler soil temperature that caused the delay in tasseling of corn plants (Halvorson et al., 2006).

In terms of CO$_2$ emissions, many studies have shown the negative impact of tillage. Soil tillage management is one important operation in crop production, which can be strategized to reduce the emission of CO$_2$ to the atmosphere by increasing the soil organic carbon (SOC) content. Several forms of tillage have been used throughout different parts of the world which can be summarized into no-tillage, minimum tillage, conservation tillage, and conventional tillage (disk tillage). Research studies have shown that among these different practices, the no-till system is very effective in reducing soil erosion (Didone et al., 2019) because of less soil disturbance and reduced fossil fuel consumption due to limited machinery utilization. A study of Barreiros et al. (1996) showed that no-till could reduce up to 60% of soil loss from splash erosion as compared to a conventional plowed field. More importantly, no-till systems can reduce the emission of CO$_2$ (Rusu et al., 2015; Auler et al., 2019) into the atmosphere compared to the other methods of tillage. This is because, under conventional methods, organic matter decomposition is much faster, resulting in CO$_2$ emission from the soil (Bauer et al., 2006). The cultivation of soil under conventional tillage favors the decomposition of organic matter due to induced aeration. The oxidized condition in conventional tillage makes the different decomposing microorganisms work better. Microbial community composition is also reported to be affected by this different tillage system. Mbuthia et al. (2015) found that no-till systems had significant gram-positive bacteria, actinomycetes, and mycorrhizae fungi fatty acid methyl ester biomarkers compared to tilled soils. Key enzymes associated with C, N, and P cycling also are significantly higher under no-till, indicating a favorable cycling condition of these nutrient elements.

Annual estimated CO$_2$ emissions were estimated at 13.34 and 9.39 Mg CO$_2$ ha$^{-1}$ for conventional tillage and no-till, respectively, in a 5-year no-till experiment on Mollisol soils (Li et al., 2013). Seasonal variation in CO$_2$ emissions is said to be affected by both temperature and moisture. Xiao et al. (2019) reported that soil CO$_2$ flux had a strong seasonal pattern where higher fluxes were measured with an increase in tillage frequencies in a typical karst calcareous soil in spring, summer, and autumn. Differences in the mean annual precipitation could influence the distribution of SOC and soil structural properties within the soil profile (Blanco-Canqui et al., 2011), which could also affect CO$_2$ emission. Much of the difference in SOC between a no-till system and conventional system, though was significantly greater near-the soil surface. Alvarez et al. (1995) reported stratified biomass C and soil basal respiration on the surface soil of a 12-year no-till system. A possible mechanism that is responsible for the increase of SOC in no-till soils is the lower organic matter mineralization rate (Bono et al., 2008). This could be due
to the improvement of soil structure. Alvarez et al. (1995) observed an improvement of soil structure through an increase in the mean weight diameter of aggregates observed in the no-till system. Tillage frequency directly affects changes in the large macroaggregates (Xiao et al., 2019), which are very important in protecting the SOC by limiting its accessibility to microbial decomposition. The physical protection of aggregate played an important role in stabilizing the occluded particulate organic matter before being further stabilized by organo-mineral interaction (Conceicao et al., 2013). A study in North Dakota on silty clay soil showed that different fractions of SOC pool respond to tillage. Coarse particulate organic matter (physical) was found to be the most sensitive fraction to tillage (Awale et al., 2013). This was followed by cumulative mineralizable C (biological) and permanganate oxidizable C (chemical). Similar findings were observed by Alvarez et al. (1995), where basal respiration per biomass was said to be regulated by coarse plant debris that accumulates on the soil surface.

**Coal**

One of the oldest and most abundant sources of energy is coal. The abundance and simplicity of how one can obtain power from coal are what makes it so appealing to man and the energy industry. Furthermore, it is readily available and shallow in the earth’s crust all over the world. This, in turn, makes it a leading candidate to produce power for the masses. Coal is a group of rocks blackish/brown and is mostly organic. Whereas coal’s little brother is called peat, it is in clumps of a dead plant matter. Usually, peat has over 50% water content; peat can at some point in time turn into coal under the right conditions. The main difference in peat and coal is that coal can be a combustible substance. The transformation from peat significantly increases the C in coal (Schopf, 1966). This enhancement in C will be released into the atmosphere when coal is burned for energy. There are estimates of one trillion tons of coal in the world and almost triple that of the world’s other energy resources. The Energy Information Administration (EIA) predicts that the United States will level out and start to decrease its coal use around 2030. With the air quality diminishing every day, the time to fix this is now! They also predicted that the current amount of coal would increase from 1.16 billion tons to 1.43 billion tons of coal a year. Over 80% of the coal is being used to produce electricity (Bartis et al., 2008). Coal alone is the leading source of the world’s C emissions, with about 13 billion tons of C released into the atmosphere every year. The best way to reduce our C footprint is to update coal plants with the newest and best technology to make them more efficient. If all coal, burning energy plants in the world were up to date, C emissions would be reduced by 40%. The average cost to update these plants is 200 million US dollars (Morse, 2012).

For the past 13 years, China has led the world in coal consumption, as well as C emissions. China produces 46% of the world’s coal and uses 49% of it every year. The ten countries that use the most coal account for 90% of the world’s use (Ayoub, 2014). China currently uses almost four times more coal than any other country. The U.S. is second using 12% of the coal (EIA,
China is leading in CO$_2$ emissions, with an annual output of 6.1 billion tons. This is 1.5 billion tons per year more than the U.S. (Kuby et al., 2011). In the U.S., Wyoming produces the most coal, followed by West Virginia, whereas Montana has the most coal reserves (Bartis et al., 2008). Brazil is the eighth leading emitter of CO$_2$ in the world, and third in the southern hemisphere. In developing countries, the reliance on coal will rise, with more of the population’s homes being equipped with electricity (Losey et al., 2006). Egypt has been traditionally an energy exporter up until now, with their natural gas reserves depleting, and with a readily available coal source, their energy demand has risen 56% in the past decade. Egypt is the world’s leading exporter of cement, and all the cement plants demand a lot of energy. Most recently, they have even reduced production by 11%. All of these shortages and the people have started a group called “Egyptians against coal” to try to reduce the pollution of coal in their country (Zayed and Sowers, 2014). India is another rapidly modernizing country needing more power. By 2030, India will need six to seven times more electricity produced than what they are currently producing. India has an abundant source of readily available coal reserves, with roughly 56 to 70 billion tons. A lot of the coal they are mining and have in reserves is poor in quality. India has a substantial amount of mercury in its coal that can be converted to a gas in the burning process. Carbon dioxide emitted from coal plants is the single largest pollutant from India. Currently, India is inadequate in updating coal plants and thus reducing CO$_2$. However, their solution is using compressed natural gas and then ship it elsewhere and inject it into the subsoil (Chikkatur and Sagar, 2009).

Bretey (1964) stated that understanding how to transport coal effectively was the key to a cheaper source of power. To make effective power in plants they must make “coke,” this is the carbonization process of coal at a high temperature ~1100-1200$^\circ$C. The better the coke quality, the lower CO$_2$ production and efficient power with less coal used (Vasko et al., 2005).

Mercury emissions in China are greater further west than east; this is due to the concentration of mercury in the coal. China has seen a 5% increase in mercury emissions per year. This coal source can release 0.30 mg per kg of coal (Zhang et al., 2002). Acid rain is possible around coal plants with high amounts of sulfur that can be released in the combustion process. Pair this with smog from the CO$_2$ resulting in a polluted city. Coal can produce 1.8 more times CO$_2$ than natural gas and 1.2 times more than oil (The Committee on Health and Environmental Effects of Increased Coal Utilization, 1980). Coal can be converted to a combustible liquid that, when burned, does not need to be as hot nor will break as many bonds as traditional usage. These bonds not being broken will contribute to less toxic byproducts in the atmosphere. The process of converting coal into a liquid is called hydrogenation. The downside to this process is it produces a carcinogen and where workers over ten years in the plant reported getting skin cancer. The emission of Benzo [a] pyrene can be a significant contributor to cancer. Coke plants have a high risk of lung cancer, and this near 2.5 times higher than steelworkers (EHP, 1976). The
Congressional Research Service proposes that a tax be applied to coal-burning plants and to tax their emissions. They believe that the tax will make producers seek cleaner energy and reduce CO2 and sulfur emissions (Schlottmann and Abrams, 1977).

With a growing and westernizing population, energy for all is a top priority. The next would be to make clean and efficient power for improved environmental health for generations to come. This problem needs to be urgently addressed, with critical thinking, along with a logical process. Some have dealt with this daily. No pointing fingers, the world combined needs to agree on this and put it into action with dignity.

**Automotive Impact**

Many chemicals come from the automotive industry. With the rise in population, increased demand for transportation exists. With this rise, there is a greater need for fuel and has led people to explore alternative energy sources outside or in combination with fossil fuels (Jing et al., 2020). Some reasons for the broadened search is to lower the dependence on non-renewable energy sources and to reduce the harmful effects of chemicals expelled from the combustion of fossil fuels such as gas and diesel. Alternate fuels such as ethanol, biodiesel, liquid petroleum gas, compressed natural gas, and other alcohols have all been shown to diminish the amount of \( \text{N}_2\text{O} \), \( \text{CO}_2 \), and other chemicals that harm the ozone (Verma et al., 2018).

Fuel economy has been looked at to determine if there is a correlation between the miles per gallon consumed and the number of emissions released (Harington, 1999). A study done in the late 1990s showed that there was a correlation when broken down by vehicle group. In a comparison of cars with lower fuel mileage, an increase in grams per gallon of emissions was noted. Similar results were seen when comparing trucks. One way to reduce emissions is to raise the fuel efficiency of our vehicles (Harrington, 1997).

The fuel efficiency of today’s vehicles is much greater than that of years past. When comparing a car from 2000 to the same equipped vehicle today, the fuel economy goes from 22 mpg to 29 mpg (Xie and Lin, 2017). This was shown to be a 25% increase in fuel efficiency. That aligned with today’s higher mixed fuel will lead to a much lower effect on the atmosphere in comparison to older vehicles (Xie and Lin, 2017). Both diesel and gasoline fuels have some form of biofuel added to them. One thought behind this is it reduces the fuel cost and allows vehicles to be eco-friendlier.

Blending fuels come from a combination of sources. When looking at a mixture of biodiesel and liquid petroleum gas, it is seen that there can be a significant reduction in soot. This is due to the liquid petroleum gas acting as a limiter in the combustion of biodiesel when used in a common rail diesel vehicle. With the reduction of soot, reduced amounts of C molecules are released into
the atmosphere (Pastor et al., 2020). When additives from lemon and orange peels are incorporated into the biodiesel, there can be reduced amounts of pollutants leaving the vehicle. Lemon peel derivatives were shown to decrease fuel use when breaking, while orange peels reduced carbon monoxide (CO) amounts in half (Sheriff et al., 2020). Hydrogen enriched gasoline was found to reduce the number of hydrocarbons and \( \text{N}_2\text{O} \) expelled from the engine.

There are vehicles today that run entirely on biofuels. These vehicles could be found within both diesel and gasoline vehicles. Gas vehicles that run completely off ethanol are called flex-fuel. When running flex fuel, there is usually a two to three-mile per gallon increase compared to gasoline. These vehicles can be used with either gasoline or ethanol. The one downfall of running straight ethanol is the wear and tear on engine components (Sheriff et al., 2020).

Biofuels in diesel vehicles showed promise in developing countries due to the availability of old grease that is a much cheaper source of power after some refinement. This could change the ability of many countries to be more self-reliant. This also lowered emissions in these areas and allows for another revenue source for countries that are not rich with fossil fuels (Liaquat et al., 2010).

Another alternate energy source for vehicles is electric vehicles. When testing complete electric vehicles, there are limited greenhouse gas emissions at the time of use (Jing et al., 2020). These vehicles can produce the same power and torque as their combustion counterparts. Although no fossil fuels are being burnt at the time of operation, the power comes from burning coal or other energy sources that all lead to the emission of gasses into the atmosphere. Electric energy has extremely low efficiency due to the major losses it will have within the transportation and in power lines. Carbon dioxide emissions from an electric vehicle are approximately a third of that produced by a gasoline vehicle (Jing et al., 2020). There are greater efficiencies seen when looking at vehicles that are both electric and regular fuel, such as gasoline or diesel (Patil et al., 2016). With the rise of alternative electric sources such as wind and solar, the ability for electric vehicles to limit the greenhouse gas’s effects on the atmosphere will be significant (Ehrenberger et al., 2019).

These alternate energy sources are helpful for not only people around you but worldwide. The ability to make high-quality fuel from plants allows for developing countries to have a clean-burning fuel at a lower cost. Numerous plant based products can be transformed into biofuel. Any crop that has a high energy reserve in the stalk or seed can be used. Another way to make these fuels is by extracting used vegetable oil. This is a great way due to the number of restaurants that need a place to go with their used grease. The third way is to synthesize it from algae. All of which will arrive at the same final product (Demirbas, 2010).
Solar energy is a great form of energy that may not directly attach to the vehicle itself but will power it. This is one of the cleanest forms of energy for a car due to how it is captured. The photosensitive cells are activated by the sunlight storing its energy into batteries for use later. This energy is then transferred to the vehicle when charging and then again stored in a large number of batteries. Although this does not allow for emissions, it does, however, still have an environmental impact. This impact is due to the disposal of batteries after they are no longer working. These batteries contain either acid or lithium depending upon the make and model (Charles et al., 2019).

**Summary**

Students in an advanced nutrient management class were assigned specific topics based on their interests as it relates to challenges present that surround global warming, and those are summarized here in a review paper format. This review covers a wide range of areas comprising causes, effects, and solutions to address global warming. The causes included contributions from different sectors such as the food industry, coal industry, and agricultural inputs. Increased atmospheric CO$_2$ coming from wildfires and that encountered via the acidification of soil and oceans is also discussed. Lastly, solutions are suggested including changing diets, monitoring weather, adoption of no-tillage, reforestation, improving fertilizer efficiency, and more efficient use of transportation and coal resources. Finally, educating our global population is paramount to achieving any kind of lasting impact.

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