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Climate-change and Greenhouse-gas Basics

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What is Climate Change?

Climate change is the long-term shift in global air temperatures and weather patterns, predominately driven by increased atmospheric greenhouse gas (GHG) concentrations from human activity. Although natural fluctuations of climate have been observed on cycles of 10000 years from geological evidence, human activity created a disturbance in the cycle that poses a threat to worldwide societies. Climate change has led to regional increases in extreme air temperatures, flooding, severe drought, and severe weather events, such as tropical storms (IPCC, 2023). The increased extreme weather from climate change is expected to reduce crop yields and harm crops from greater night-time air temperatures, more variable precipitation, and increased pest pressure (EPA, 2024a). In addition, climate-change-related deaths along with food, water, and vector-borne diseases have increased due to shifting weather patterns in all regions around the globe (IPCC, 2023).

Cause

Climate change is mainly driven by the greenhouse effect, which occurs when relatively energetic (i.e., shorter wavelength) visible radiation from the sun passes through the atmosphere, is absorbed by objects on the Earth's surface, and is then re-radiated back into the atmosphere as lower energy (i.e., longer wavelength) infrared radiation. The re-emitted infrared radiation is then absorbed by certain compounds (i.e., GHGs) in Earth's atmosphere that causes atmospheric heating. Increasing atmospheric GHG concentrations have magnified the natural greenhouse effect, leading to an increase in annual global air temperature in many regions. The increase in atmospheric GHG concentrations is driven mainly by GHG emissions from transportation (28% of total U.S. GHG emissions), electric power production (25%), industrial processes (23%), and agriculture (10%).

Greenhouse Gases

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), and chlorofluorocarbons (CFCs) are the major GHGs that trap heat in the atmosphere. Carbon dioxide naturally enters the atmosphere from respiring or "breathing" plant roots, animals, and microorganisms, but burning billions of tons of fossil fuels for energy, transportation, and operating machinery has resulted in millions of additional tons of CO_2 entering the atmosphere each year (EPA, 2024b; USEIA, 2024). Methane is naturally produced when organic matter is broken down under anaerobic (i.e., without oxygen) conditions, (e.g., in wetlands) but about 60% of CH_4 emissions result from anthropogenic activities such as fossil fuel burning, livestock production, flood-irrigated rice (*Oryza sativa*) production, and waste management (NASA, 2024). Nitrous oxide is produced as a byproduct of denitrification,

which is the conversion of nitrate (NO_3-) to dinitrogen gas (N_2) under anaerobic conditions, and by the combustion of organic materials containing nitrogen. Human activities contributing to increased nitrous oxide emissions to the atmosphere include the application of N fertilizers to soils used for crop production, the industrial production of N fertilizers, and the burning of fossil fuels and solid waste. Agricultural soil management is the largest anthropogenic source of agricultural emissions and accounted for ~ 74% of N_2O emissions and 4.6% of total GHG emissions in the United States (US) in 2022 (EPA, 2024b).

While atmospheric concentrations of CH_4 (~ 1.8 ppm) and N_2O (~ 0.336 ppm) are much lower than that of CO_2 (~ 419 ppm), CH_4 and N_2O are often said to be more "potent" GHGs than CO_2. This is because CH_4 and N_2O are much more efficient absorbers of infrared radiation than CO_2. Methane is approximately 27 times more efficient at absorbing infrared radiation than CO_2, while N_2O is 273 times as efficient.

Another factor that complicates predictions of the long-term effects of increasing GHG concentrations involves differences in the persistence of GHGs in the atmosphere. Unlike CO_2 and water vapor, CH_4 and N_2O slowly degrade in the atmosphere, which eventually reduces their atmospheric concentrations. As a result of these reactions, CH_4 has what is known as an average atmospheric lifetime of 11.8 years while N_2O has an average atmospheric lifetime of 109 years (EPA, 2024c,d). Carbon dioxide cannot be represented with an average lifetime because CO_2 is not degraded over time like CH_4 or N_2O (EPA, 2024c).

Similar to CH_4 and N_2O, CFCs are persistent in the atmosphere with lifetimes ranging from 45 to 1000 years. However, CFCs are not natural or agricultural in origin, such as some sources of CH_4 and N_2O, instead, CFCs are commonly from refrigerators, air conditioners, and aerosol spray cans. Chlorofluorocarbons are a particularly potent GHG because CFCs are at least 4000 times more potent at absorbing infrared radiation than CO_2, and CFCs deplete Earth's ozone layer that protects the Earth from harmful ultraviolet radiation (EPA, 2024e).

Water vapor traps more heat than CO_2, CH_4, and N_2O, but significant changes in water vapor concentration are not directly impacted by humans. Water vapor enters the atmosphere through evaporation, which has increased about 1 to 2% every decade since the 1980s due to the increased air temperature resulting from CO_2, CH_4, and N_2O emissions (NASA, 2022).

Common GHG Metrics

Multiple metrics can be used to evaluate GHGs. One metric is a flux, which quantifies the GHG concentration change over a specific period of time and area. The GHG concentrations are typically measured over the course of five minutes to one hour to determine an hourly flux. A flux value is calculated by multiplying the gas concentration change over time by chamber volume, and then dividing by the surface area (Parkin & Venterea, 2010). Flux may be expressed in units of mg m^{-2} hr^{-1}, ppm m^{-2} hr^{-1}, or kg ha^{-1} day^{-1}. A positive flux indicates gas leaving the soil and entering the atmosphere, while a negative flux indicates gas entering the soil from the atmosphere.

A second commonly used GHG metric is emissions, which is the sum of fluxes over a specific period of time (e.g., a week, a month, a growing season, or a year) and is usually determined by linearly interpolating measured fluxes between measurement dates. Emissions describe the total GHGs emitted during a period of time, usually a full crop growing season or full year. Common GHG emissions units are lbs ac^{-1} or kg ha^{-1}, and emissions are reported for a single gas.

A third standardized metric that quantifies the combination of CO_2, CH_4, and N_2O emissions is global warming potential (GWP), which is the sum of seasonal or annual CO_2, CH_4, and N_2O emissions. Methane and N_2O emissions are converted to a carbon-dioxide-equivalent (CO_2e) value by multiplying by ~ 27 for CH_4 and ~ 273 for N_2O to account for the two gases' ability to trap more heat in the atmosphere compared to CO_2 (IPCC, 2021). Global warming potential is usually represented in lbs ac^{-1} or kg $ha^{-1}$of CO_2e.

A fourth metric is emissions intensity or GWP intensity, which is the sum of season-long emissions or GWP per unit of crop yield. This is a useful metric for evaluating how the intensity of agriculture practices impacts GHG emissions. The intensity metric is reported as lbs of gas per lbs yield or kg gas per kg yield. Thus, decreasing emissions without sacrificing total yield would result in a lower emissions intensity and indicates a system managed to reduce GHG emissions without sacrificing crop yield.

GHG Measurement Methods

Greenhouse gas concentration measurements are typically measured in one of two ways. One approach is the closed-chamber method that uses a sealed

polyvinyl chloride (PVC) chamber from which a gas sample is collected manually with a syringe multiple times over about a period of 1 hour (Figure 1). The syringe-collected gas sample is then transferred to a vial that is analyzed by gas chromatography to determine the gas concentration at specified times, which is then used to calculate the gas flux.

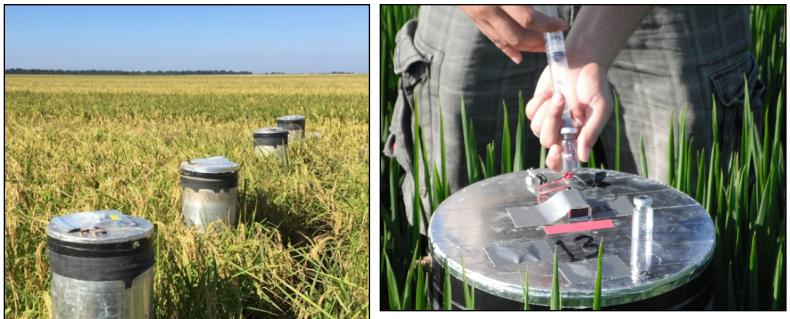

Figure 1. Static-chamber, syringe-sampled method for measuring greenhouse gas concentrations. Large-diameter chambers installed in a rice field (left panel) and chamber cap and syringe-sampling procedure (right panel).

Figure 2. Flow-through chamber and two LI-COR greenhouse gas analyzers (left panel) and a flow-through chamber and a Gasmet analyzer (right panel) that simultaneously measure carbon dioxide, methane, and nitrous oxide concentrations in the field.

A second method utilizes a field-portable, analyzer system that can be connected to a flow-through smart-chamber or a static, closed-chamber system with a pump. The flow-through-chamber method pumps air from a closed, mechanical chamber to one or two gas analyzers, for example LI-COR Inc. analyzers (Lincoln, NE) or a Gasmet Technologies Oy analyzer (Vantaa, Finland), that measure and record a GHG concentration at a specified time interval (e.g., once every second for LI-COR analyzers or once every 20 seconds for the Gasmet analyzer) for five to eight minutes (Figure 2). The large quantity of GHG concentration data from the flow-through-chamber method generally results in a more accurate GHG flux estimation in less time.

Similar to the field-portable, flow-through chamber, an automated, long-term, flow-through chamber system can be semi-permanently installed in a field to collect GHG concentration data on a more frequent basis than the hand-held, field-portable systems. Once installed and connected to a solar power source, the long-term, flow-through chamber system is programmed to automatically close the chamber, measure and record GHG concentration data, and re-open the chamber multiple times each day if desired (Figure 3). The automated, long-term, flow-through chamber system provides even more GHG concentration data than the previous two methods and can be operated remotely without going to the field to manually collect samples of conduct measurements. Other measurement techniques exist too.

Figure 3. Automated, long-term, flow-through-chamber system with solar power supply (left panel) and four connected sampling chambers (right panel) that stays in the field and simultaneously measures carbon dioxide, methane, and nitrous oxide concentrations multiple times per day. Two chambers are in a cover-crop treatment (right panel, left), while two chambers are in a no-cover-crop treatment (right panel, right).

Conclusions

Agriculture is continuing to impact climate change from GHG emissions. Basic knowledge of GHGs, measurement metrics, and measurement techniques can lead to increased understanding and eventually to widespread implementation of management practices that can reduce GHG emissions and agriculture's contribution to climate change and environmental quality. Greenhouse gas studies also provide keys to better understanding nutrient management and improving soil health, which is a direct benefit to maximizing agroecosystem productivity.

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