Case Study:

Climate Change and Agriculture in New York State

Partner Organization: Cornell Institute for Climate Change and Agriculture
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Authors:
James Monahan, Cornell University (jbm329@cornell.edu)

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Climate Change and Agriculture in New York State

James Monahan

Introduction

Climate change poses unprecedented challenges for agricultural production across the world. Climate change has been linked to warmer temperatures, drought, heavy rainfall, flooding, frost damage, increases in disease and pest pressure, and increases in severe weather (Melillo, Richmond, & Yohe, 2014). These climate-related phenomena have in many instances caused substantial crop damage and created growing uncertainty among farmers across the world. While climate change will have an impact on agriculture worldwide, not all farmers will be impacted equally or experience the same kinds of effects. In some regions, such as Southeast Asia, the climate is expected to become drier (Nelson et al., 2009), while in other parts of the world, such as the Northeastern United States, precipitation levels will likely increase slightly but rainfall events are expected to become increasingly variable (Wolfe et al., 2011). Throughout most of the United States, the length of the growing season will increase. For states like New York changes that include warmer winters, earlier springs, and longer growing seasons may present an opportunity for agricultural producers, but those changes will also bring increases in pest pressures and may require farmers to plant new crop varieties that grow better in warmer climates. No matter what kind of shifts take place, positive or negative, growers will be required to adapt their agricultural practices to a changing climate if they want to maintain the viability of their farms. **Climate change adaption** refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (United Nations Framework Convention on Climate Change, 2014).

Not only is agriculture impacted by climate change, but it has also become an important driver of climate change (Intergovernmental Panel on Climate Change [IPCC], 2007). Globally, agriculture accounts for about 14% of the greenhouse gas (GHG) emissions that are causing climate change, with deforestation for the purpose of developing agricultural land being a major source of emissions (IPCC, 2007). In the United States, the world's second largest producer of greenhouse gas emissions, agriculture accounts for about 10% of total emissions (See figure 1). Deforestation, however, is not a major contributor in the United States. U.S. agricultural emissions primarily pertain to the use of nitrogen fertilizers and methane from livestock (EPA, 2014a). What makes agricultural emissions a particular concern is the high levels of nitrous oxide (N_2O) and methane

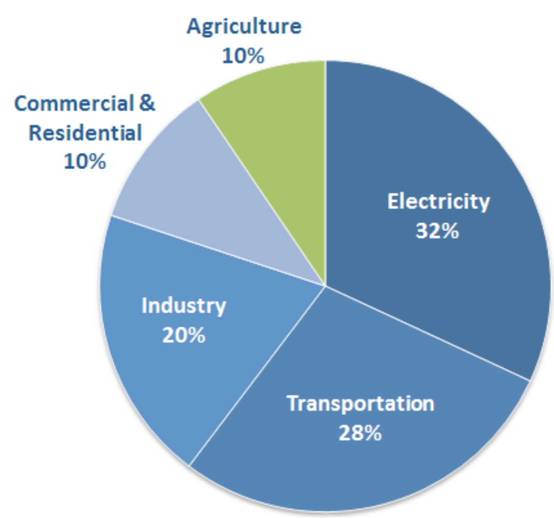

Figure 1. *GHG Emissions by economic sector in the United States (EPA, 2014).*

(CH_4), which have much stronger global warming potentials than carbon dioxide (CO_2); for example, nitrous oxide has a global warming potential 310 times that of CO_2 and remains in the atmosphere for 114 years. (EPA, 2014b).

Just as farmers will need to adapt their growing practices for a changing climate, farmers need to contribute to reducing their greenhouse gas emissions. **Climate change mitigation** is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2007). Farmers can accomplish this by adopting agricultural mitigation practices, such as using renewable energy on their farms, reducing the use of nitrogen fertilizer, and putting soil management strategies in place, including reduced tillage and the planting of cover crops. Climate change adaptation and mitigation are intrinsically linked; the greater the levels of mitigation, the less adaptation that will be necessary. While reversing climate change is unlikely, scientists are hopeful that if humans reduce their emissions of GHG's, the earth's average temperature will not increase by more than an additional 4 degrees Fahrenheit. For agriculture, accomplishing widespread adoption of agricultural adaptation and mitigation practices is a difficult challenge; it will involve contributions from federal and state agencies, researchers, businesses, and individual farmers working together to share information and best practices. In the northeast, Cooperative Extension services will play an important role in educating farmers about the risks climate change poses to agriculture, as well as assisting in the development and implementation of solutions to farming in a changing climate.

Agriculture in New York State

Agriculture in New York State provides a valuable entry point into understanding the impact of climate change on the Northeastern United States. New York agriculture is already experiencing both the positive and negative effects of climate change. Many of New York's high value agricultural commodities such as apples and dairy are threatened by climate change, while the state's European wine grapes are poised to benefit from warming temperatures. New York is also a valuable case study for exploring climate change and agriculture because it leads the Northeast in on-farm renewable energy production, which is an important component of climate change mitigation. Furthermore, New York agriculture is characteristic of agriculture in many other states throughout the Northeast. Relatively small–medium sized farms with a diverse set of commodities, including dairy, grains, vegetables, orchard fruits, berries, ornamentals, maple syrup and forestry products, characterize agriculture in the Northeast.

With over 36,000 individual farms, agriculture plays an important role in New York State's economy. In particular, these farms are a vital part of upstate New York's economy, producing nearly 5 billion dollars annually in agricultural goods (DiNapoli, 2012). In addition, the state's agricultural economy plays an important role in the food supply system that supports agri-service and food processing businesses, such as New York's growing Greek yogurt industry. In particular, New York agriculture is a national leader in dairy, grape, apple, cabbage, and maple syrup production (USDA, 2010a). In addition, New York has the fourth-largest number of organic farms in the country, which is a growing sector in the agricultural economy (USDA, 2010b).

Dairy is New York's largest agricultural industry and generates approximately half of the economic value of the state's agricultural goods. Other high-value crops are corn grain, corn silage, hay, and apples. Grape production is also very valuable, being valued at 68.4 million dollars annually. Although relatively modest when compared to the value of grain corn at 460 million dollars, when grapes are processed into wine and juice they gain a significant added value. Grape, wine, and juice production, coupled with tourism to New York's vineyards and wineries is estimated to contribute 3.8 billion dollars annually to the state's economy (Stonebridge Research Group, 2014).

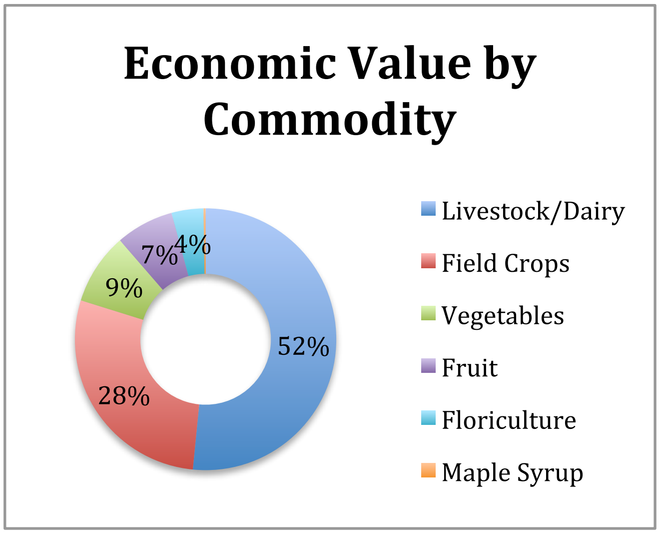

Figure 2. *Economic Value by Commodity (New York Dept. of Agriculture and Markets, 2012)*

While the average New York farmer is currently a fifty-six year-old white male, this characterization is changing. In recent years there has been a slight increase in the number of young farmers and a substantial increase in the number of female farmers (USDA Census, 2007). This trend has important implications for climate change, as young people and women are more likely to believe in the link between human activity and climate change (McCright, 2010). This fact may have implications for these demographic groups' willingness to adopt agricultural adaptation and mitigation practices (Arbuckle, 2013; Stuart, Schewe, & McDermott, 2014). In New York the average annual farm income is $32,000, but for about 46% of the state's farmers, farming is not their principal occupation. The number of farmers who derive income from other sources may continue to rise if the effects of climate change make crop production increasingly less predictable and profitable.

Agricultural land, which includes field crops, orchards, and pastures, covers 23% of the state (New York State Department of Agriculture and Markets [NYSDAM], 2014). Most of this land can be found in the Southern Tier, Central NY, Western NY, The Finger Lakes, and the Hudson Valley. On average these farms are relatively small in size, averaging about 197 acres, which is about half of the national average. Small farms dispersed throughout the state play an important economic role in rural communities and are a critical component in the development of local food systems. Small farms and low-income rural communities may be some of the first groups of people to experience economic hardship if climate change leads to declines in agricultural productivity (Wolfe et al., 2011). This is because small farms and rural communities may be less able to employ adaptation strategies that require significant capital investments and are less likely to benefit from economies of scale (Wolfe, et al., 2011) The disproportionate impact that climate change will have on low income rural communities raises questions of environmental justice with regard to the impacts of climate change. Increased economic pressure in these communities may lead to the consolidation of small farms into larger farms and agribusinesses. The number of farms and the acreage dedicated to agriculture in New York has been declining over the past decade, decreasing by about 3% per year, while the number of large farms over 2,000 acres has increased (USDA Census, 2007). The consolidation of smaller farms has been particularly prevalent in the dairy industry. However, declines in the number of farms have not always equated to declines in production levels. Understanding farm size is important because the scale of an agricultural operation plays an important part in determining a farm's GHG emissions, as well as the kinds of adaptation and mitigation strategies that are economically viable.

Not only is agriculture important economically, but it is also part of the cultural identity of many rural communities in upstate New York. Some farms in New York have been operated by single families for as many as five generations. Central New York is home to several Amish and Mennonite communities, two groups with deep ties to an agricultural way of life. Lastly, upstate New York's rural character and cultural life is an important tourist attraction for residents from the state's cities; agri-tourism, which often involves urban and suburban residents visiting rural areas to engage in activities such as apple and pumpkin picking, is especially beneficial to the Hudson Valley because of its close proximity to New York City.

The Role of Cornell Cooperative Extension

For over 100 hundred years, Cornell Cooperative Extension (CCE) has helped serve the needs of farmers in New York State. CCE, like all state extension services, has its roots in the establishment of agricultural colleges as a result of the Morrill-Land Grant Act and the passing of the Smith-Lever Act, which created the Cooperative Extension system. Traditionally, extension services have helped farmers to improve productivity on their farms by advising them on the latest agricultural practices. Promoting agricultural best management practices is still a primary role of extension services, however over time CCE has taken on new missions including community economic growth, health and nutrition, and sustainable environmental practices. CCE's commitment to sustainable management practices coupled with its strong connection to local communities make it a powerful resource for educating farmers on adaptation and mitigation practices, as well as helping in the implementation of these new management strategies.

Climate Change and Agriculture in the Northeast: Effects and Adaptation [1]

Temperature and Precipitation

Over the last 100 years, the average annual temperature in the Northeast has risen by 1.8 degrees Fahrenheit, which is higher than the global average of 1.1 degree

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[1] The following section draws heavily from Professor David Wolfe's chapter on climate change in agriculture in the NYSERDA ClimAid report. See citation below:

Wolfe, D., Comstock, J., Lasko, A., Chase, L., Fry, W., Petzoldt, C.,… Vancura, P. (2011). Chapter 7: Agriculture. In Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S, & Grabhorn P. (Eds.). *Responding to Climate Change in New York State.* Albany, NY: NYSERDA.

(Wolfe et al., 2011). Higher temperatures could mean longer growing seasons, which could provide opportunities for double cropping of some crops such as raspberries, and the planting of higher yielding varieties of crops such as corn. However, in some instances higher temperatures could also create heat stress, which could lead to decreased yields, particularly in grain crops, and poorer crop quality in some vegetables and fruits.

While the annual precipitation averages in the Northeast have increased modestly over the past fifty years, there has been a, substantial, 67% increase in the amount of heavy precipitation in the region (Melillo, Richmond, & Yohe, 2014). More extreme precipitation events have contributed to flooding of fields, soil erosion, and soil compaction, all of which can negatively impact soil health and crop yields. Heavy rainfall can also lead to delays in getting access to fields and the use of farm machinery at critical times of the year. In addition to extreme precipitation, New York has experienced periods of extended drought, which can limit water availability and reduce yields. As the average temperature in the state continues to rise these shifts in precipitation are expected to intensify.

In New York, heat sensitive crops, which include potatoes, cabbage, and apples, will likely become more difficult to grow. However, warmer temperatures will likely make it easier to grow European wine grapes, peaches, melons, and tomatoes. Some existing crops such as apples may continue to grow, but only particular varieties. Farmers can also adapt to climate change include changing planting dates to avoid extreme rains, high temperatures, or frosts and the planting of new varieties that can take advantage of longer growing seasons to produce higher yields (Hoffman and Smith, 2011). In order to counteract increases in weather variability, farmers may have to plant a diverse array of crop varieties. For example, a corn farmer may be able to take advantage of longer growing seasons by planting a higher yielding corn variety, but that variety may be less resistant to flooding or frost. Therefore, that farmer may want to plant a diverse set of varieties to ensure that she or he does not lose the entire crop from an unforeseen weather event (USDA, 2013).

To overcome increases in heavy precipitation, farmers may need to invest in drainage systems to prevent crop damage and soil erosion. These systems can be expensive, but may be necessary. Farmers can also rely on the use of cover crops, particularly during the offseason, to help reduce soil erosion from extreme precipitation and wind events. Other potential solutions include improving soil drainage by increasing soil organic content and planting flood tolerant crops. To overcome periods of drought, farmers may need to invest in irrigation and consider planting drought resistant varieties.

Disease and Pest Pressures

Climate change is expected to lead to increases in disease and pest pressure for agriculture in the United States. Warmer temperatures will extend growing seasons but they will also allow for more generations of pests to develop within a single year. Warmer winter temperatures will also lead to higher survival rates of overwintering pests; an earlier arrival of spring temperatures will mean more insect damage on crops earlier in the season (Wolfe et al., 2011). Warmer temperatures may also allow pests such as the brown marmorated stink bug to expand northward and establish larger populations within the state. These changes may require many farmers to increase pest control. Increases in pest control will incur greater expenses, time and energy for agricultural production. Plant pathogens may benefit for many of the same reasons as insect pests, including higher survivorship rates and expansion northwards. However, temperature is not the only factor that may increase pest pressure. Heavy rainfalls may benefit some leaf pathogens and will likely wash pesticide residues off of leaves; on the other hand, heavy rainfall may inhibit other pathogens, as may periods of drought. Higher levels of CO_2 may also favor some insects, pathogens, and weeds.

Increases in weed and pest pressure may tempt farmers to increase their use of herbicides and insecticides. Better monitoring and knowledge of these pests and using strategies such as integrated pest management (IPM) can help farmers reduce the cost of pesticides and minimize their exposure to chemical applications. When it comes to adaptation, farmers will have to employ a diverse set of methods to control for an equally diverse set of challenges.

Livestock

Increasing temperatures may pose serious risks to livestock production, particularly for cattle. Extreme temperatures can be fatal to cattle, but even modest temperatures can have an impact on productivity. These risks are particularly worrisome for the dairy industry in northeastern states like New York and Pennsylvania. Even modest increases in temperature and humidity can induce heat stress in cattle, which has been shown to lead to declines in milk production (Chase, 2006; Key, Sneerigner, & Marquardt, 2014). Not only does dairy production decrease as a result of heat stress, but cows will consume less feed and their reproductive success will decline as well. Researchers estimate that the annual cost of heat stress on cattle was nationally about 2.4 billion dollars and 24.9 million dollars in New York (Chase, 2006). Additionally, climate change may lead to greater uncertainty in feed production, which could cause significant fluctuations in livestock production costs (Wolfe et al., 2011).

As temperatures continue to rise it is likely that the economic impact of climate change on the dairy and livestock industry will continue to rise as well. Farmers will need to find ways of reducing the amount of heat stress on their animals. Some methods for accomplishing this include improving ventilation in barns, increasing water availability, changing cattle diet, using sprinklers for cooling, and improving barn insulation. Farmers may also need to consider raising cow varieties that are less prone to heat stress (USDA, 2013).

Apples and Other Perennial Fruit Crops

New York is a national leader in apple production with many varieties having been first cultivated in the state, such as Empire, Cortland, and Macintosh. Apples, like many perennial fruit crops, will likely experience positive and negative effects of climate change. Many crops and plants will likely benefit from higher levels of atmospheric CO_2. Furthermore, warmer average temperatures will mean longer growing seasons, which will favor the cultivation of apple varieties such as Granny Smith (Wolfe et al., 2011). However, apples also have been shown to be less productive during years with warm winters (Wolfe et al., 2011). Additionally, one of the most important outcomes of climate change will be greater uncertainty; the weather will become more variable and the extremes greater. Many perennial fruits are sensitive to temperature fluctuations during critical times of the year such as bud break and pollination. Consistently cold temperatures are important because they allow the physical structure of a plant to harden, which protects it from extreme cold and frost. Cold temperatures also allow plants to reserve their energy during the winter months so that they have more energy to put into new growth in the spring. While cold temperatures can be a good thing, there is a balance that needs to be maintained. If temperatures get too cold plants can be damaged and even die. Extreme cold and extreme heat could also negatively impact pollinators by reducing their populations or by disrupting the timing of pollinators with the flowering of plants (Kjohl, Nielsen, & Stenseth, 2011). In the summer and fall, extreme heat during the fruiting period could lead to declines in fruit quality, particularly among New York varieties of apple (Wolfe et al., 2011). Changes in precipitation levels coupled with high temperatures in the summer and fall may require greater use of irrigation during dry periods. Like apples, other tree fruits such as pears, plums, and peaches will be susceptible to similar extremes in weather.

Grapes

New York is a national leader in grape production. Grapes are considered a climate change opportunity crop because warmer temperatures and longer growing seasons will mean that a greater number of varieties of high value European (*Vitis vinifera*) wine grapes will be able to be produced in the region. Currently, many varieties of wine grape are unable to be grown in New York because the growing seasons are either not long enough and or the variety is not able to withstand the region's cold winter temperatures. Warmer temperatures in the region could lead to not only the growing of new varieties, but also to improved grape quality and productivity as well. These kinds of changes could make New York's grape production more competitive with grapes from California. Concurrently, and unlike New York, California is likely to experience a continued decline in the availability of water, which could raise their cost of grape production (Hoffman & Smith, 2011). While a changing climate could be a positive for some varieties of grape, it could have negative consequences too, particularly for grapes native to New York, such as Concord, Catawba and Niagara. These varieties have adapted over many years to the climate in the Northeast and are an important source of table and juice grapes. Native grapes make up the majority of New York's production. Additionally, increased temperature variability, particularly during the winter or early spring, could lead to cold damage if grape plants prematurely break dormancy. Native grapes such as Concord, may be particularly vulnerable to weather variability, as they come out of dormancy very quickly and begin rapidly producing new growth at the early onset of spring. Lastly, as mentioned earlier, warmer temperatures will lead to increases in disease pressure, and diseases such as black rot, which have typically been of greater concern in the southern United States may become more prevalent in the region.

Agriculture and Mitigation[2]

Reducing Nitrogen Fertilizer Use

Agriculture is the largest anthropogenic source of nitrous oxide (N_2O) emissions in the United States, accounting for approximately 70% of the total (EPA, 2011). Most of these emissions come from the use of synthetically produced nitrogen fertilizers, with the remaining 5% coming from animal waste (see Figure 3). While N_2O emissions are relatively low compared to CO_2 emissions, N_2O is over 300 times more effective at trapping heat than CO_2 over a 100-year period; as a result it is agriculture's greatest contributor to climate change. Farmers use synthetically produced nitrogen fertilizers because nitrogen inputs generally promote higher crop yields. Before the development of synthetic fertilizers, farmers relied on a coupled system, wherein farmers used livestock manure for fertilizer and some of that fertilizer was used to grow feed for their livestock. Synthetic fertilizers, however, allow farmers to dispense greater quantities of valuable plant nutrients such as nitrogen and phosphorous. Synthetic fertilizers have been used extensively in grain, corn, and soybean production. When synthetic fertilizers degrade they emit N_2O. Furthermore, unlike the fertilizer produced through a coupled farming system, synthetic fertilizers are produced offsite and need to be moved to farms. The production and transportation of these nitrogen-enriched fertilizers require a substantial amount of energy, likely from carbon-based fossil fuels, which in turn leads to even more GHG emissions. For these reasons the reduction of synthetically produced nitrogen fertilizers is a critical component of agricultural mitigation.

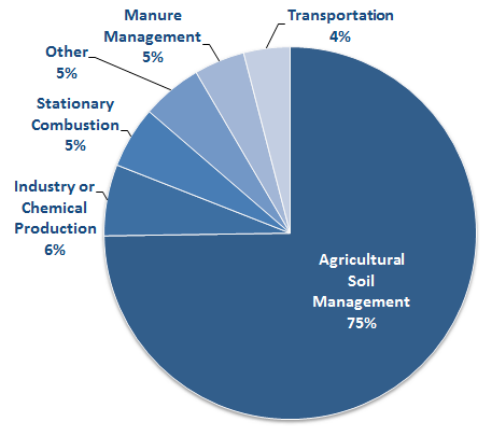

Figure 3. *N_2O emission sources in the United States (EPA, 2014b).*

One strategy for reducing the use of these fertilizers is better fertilizer management. Farmers often use more fertilizer than they need. At a given point the amount of fertilizers used stops producing a return on investment because the cost of additional fertilizer exceeds any increase in productivity. One way to improve fertilizer management will be to better educate farmers about how much is needed for a given crop at a given time. Certain times of the season may be more effective than others and being mindful of weather conditions could have an impact as well; for example, it may not make sense to spray fertilizer before a heavy precipitation event when many of the nutrients will be washed away. Furthermore, by taking advantage of Cooperative Extension services such as soil testing, farmers can have a better understanding of how much fertilizer they need to use in the first place. Distributing the same amount of fertilizer across a given field may not be efficient because some areas may need more fertilizer, while others may need less. Another promising area of fertilizer management

[2] This section draws heavily from Wolfe, D., Beem-Miller, J., Morrill-Chatrchyan, A., & Chambliss, L. (2011). Farm Energy, Carbon, and Greenhouse Gases. *Cornell University*.

is the use of precision agriculture. Precision agriculture refers to, "a suite of farm-level information technologies,[such as GPS and yield monitors that] can improve the efficiency of input use and reduce environmental harm from the overapplication of inputs such as fertilizers and pesticides (Schimmelpfennig & Ebel, 2011)." Precision agricultural technologies can help farmers to reduce fertilizer application costs and help to mitigate N_2O emissions.

Other important methods of reducing N_2O emissions include crop rotation with nitrogen-fixing crops such as legumes. Nitrogen-fixing crops remove nitrogen from the air and distribute it into the soil, which ultimately reduces the need for additional fertilizers. Another method for N_2O mitigation is to re-couple farm systems so that manure and compost can be used in place of synthetic fertilizers (Hoffman and Smith, 2011). In the Northeast this may be easier to accomplish because many small- to medium-size farms produce both crops and cattle, as opposed to other parts of the country where farming has become increasingly specialized and large-scale, producing crops like corn and wheat. Lastly, the planting of winter cover crops such as rye can be used to help keep nitrogen from leaching out of the soils during the winter. If employed correctly these N_2O mitigation strategies can be used to reduce emissions, generate cost savings in the form of less fertilizer purchases, and maintain, if not exceed, current production levels. Concurrently, fertilizer reduction is good not just for the climate but for the environment in general, as fertilizers have negative impacts on freshwater resources (Stuart et al., 2014). N_2O mitigation is a good example of a win-win scenario as it simultaneously creates cost savings for farmers and promotes environmental sustainability.

The Use of Renewable Energy

The use of on-farm renewable energy sources is an important component of climate change mitigation. Such sources commonly refer to solar panels, wind turbines, and anaerobic digesters for the production of energy. These alternative sources of energy allow farmers to reduce their reliance on carbon fossil fuels and ultimately reduce their CO_2 emissions. Solar panels and wind turbines are a good fit for farms because they will likely have the space needed to construct them. As energy prices continue to rise, these sources of energy can provide farmers with a greater degree of energy independence and cost savings over the long-term, particularly if farms are able to produce more energy than they consume. In these cases, it may be possible to sell surplus energy back to the utility company. Initial investment for these technologies can be expensive, but state and federal subsidies are often available. Other alternative energy sources include the use of biofuels such as switchgrass and corn. It may be possible for growers to use these fuels to power their own farms.

Anaerobic Digesters[3]

Anaerobic digesters (ADs) are a promising technology for climate mitigation because they can be used to directly reduce methane emissions and indirectly can help to reduce carbon dioxide and nitrous oxide emissions. Anaerobic digesters are particularly effective at reducing agricultural methane (CH_4) emissions from livestock: “If 40% of the manure in NYS was digested, it would be equivalent to removing ~215,000 cars from the road” (Pronto & Gooch, 2011). The anaerobic digestion process typically begins by aggregating organic matter, such as manure, bedding, and/or food waste in an influent pit and then agitating and pumping that organic matter into an enclosed digester vessel (See figure 4). The digester vessel is an oxygen-free environment where the organic matter can be broken down by bacteria into two byproducts: biogas and digestate. Biogas is primarily made up of methane (60%) and carbon dioxide (40%). Digestate is the material that exits the AD after the organic matter has been broken down and decomposed. Typically in the United States, as the biogas forms, it is continuously channeled into a generator where it is burned and turned into heat and electricity. The electricity that is generated from the burning of the biogas can be used to provide power to the farm and may even produce an energy surplus that can be sold back to the power utility. Cornell researchers have estimated that if half of the state’s dairy cows were to supply manure to ADs, then 45,000 homes could be powered annually (Pronto & Gooch, 2011). The digestate can be separated into dry solids that can be used for animal bedding and into liquid nutrients that can be used for fertilizer. Digesters prevent methane from being released by decomposing animal waste with anaerobic bacteria in an enclosed vessel that contains the biogas and prevents release to the atmosphere.

By generating electricity from AD-produced biogas, farmers can meet their energy needs without relying exclusively on fossil fuels, which often translates into reductions in CO_2 emissions. Finally, the fertilizer that can be produced by an AD can help to reduce farmers’ reliance on synthetically produced nitrogen fertilizers. A reduction in the use of synthetic fertilizer reduces carbon emissions from the manufacture of fertilizer. Additionally, when applied properly, liquid digestate is less likely to leach into freshwater resources and contribute to environmental problems such as nitrification.

[3] This section on anaerobic digesters has drawn heavily from the Anerobic Digester Curriculum (2011) produced by Jennnifer Pronto and Curt Gooch. This section has also built upon an online article written by Cornell Cooperative Extension Educator Elizabeth Newbold.

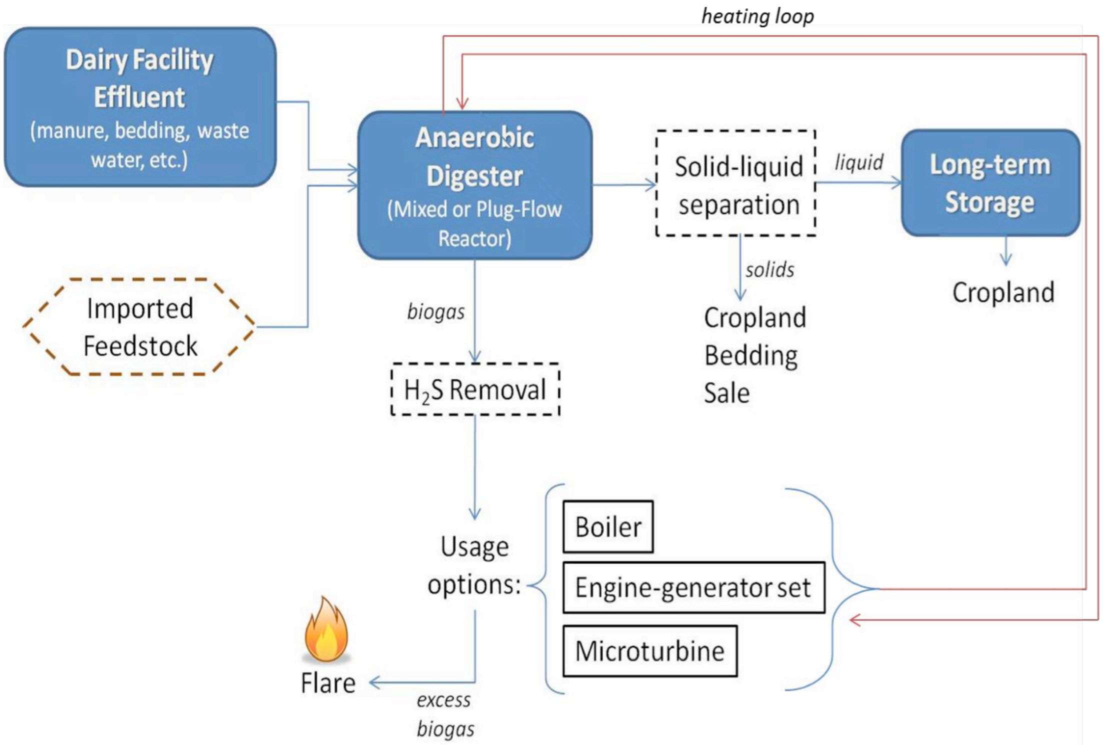

Figure 4. *Anaerobic digester process diagram (Pronto & Gooch, 2011)*

With twenty-four anaerobic digesters in operation, New York State has more digesters than any other state, with the exception of Wisconsin. In New York, digesters have been used primarily on dairy farms because a large quantity of manure is available, which is a prime material for inclusion in an AD – either alone or with other wastes. Anaerobic digesters are not recommended for operations with less than 250 cattle, and yet, even at this scale, digesters may not be profitable (Wolfe, et al., 2011). The need for a substantial herd size and the expense of building a digester, which in New York costs approximately 1.6 million dollars, means that at this time only large farms have made the investment in these systems, even with heavy subsidies from the state (Wolfe, et al., 2011). Currently, New York State and the USDA offer subsidies for the building of anaerobic digesters; in some instances, these subsidies can cover 50% of the construction cost. Subsidies play an important role in promoting the construction of digesters, however they do not guarantee that the construction of a digester will generate long term cost savings for farmers. In New York State, an economic analysis conducted on eight farms with anaerobic digesters found that only three of the farms had an economic gain as a result of operating the digester (Pronto & Gooch, 2011). All three of these farms accepted organic waste from off-farm sources and charged a fee for the inclusion of that waste (Pronto & Gooch, 2011). Incorporating local sources of organic waste is one way to improve the economic value of digesters. However, not all types of digesters are capable of accommodating different forms of organic waste. The ability for an AD to accommodate multiple waste streams should be carefully considered during the design phase of the AD (Pronto & Gooch, 2011). Additionally, a standardized carbon market that allows farmers to trade carbon credits may allow AD operators to increase revenue from their digester systems.

Concentrated Animal Feeding Operations (CAFOs) are a key source of agricultural methane emissions. In New York State, large Dairy CAFOs, with herds of 500 or more cows represent less than 4% of the states total dairy farms but house 34% of the state's dairy cattle (Overton, 2007). The increasing consolidation of the dairy industry into medium and large CAFOs may lead to an increase in the number of New York farmers with herds large enough to sustain anaerobic digesters. However, there is the potential for smaller operations to co-operatively manage a locally shared digester. It is important to keep in mind that while conservationists will likely value the mitigation capacity of digesters, mitigation may not be at the forefront of farmers' concerns. Many farmers will likely see greater value in a digester's potential to create long-term cost savings, energy independence, a reduction in the smell of manure on their farms, and the ability to market their farms as 'sustainable'. If anaerobic digesters become more widely adopted their construction costs will likely come down and the number of farms that could benefit from them should increase. Researchers are also looking for ways to produce digesters that are viable for smaller scale operations.

Carbon Sequestration

In addition to reducing CO_2 emissions through renewable energy and reductions in the use of synthetic fertilizers, farmers can also sequester carbon in soils. Trees and crops sequester carbon, but once they decompose that carbon is released back into the atmosphere; one of the advantages of sequestering carbon in soils is that if managed properly they can serve as a more stable sink. The best way to store soil carbon is to promote the soils' organic carbon content. This can be accomplished in three ways: through reduced tillage, which limits aeration that speeds up the breakdown of carbon content; through the use of carbon rich fertilizers such as manure and compost; and through the planting of winter cover crops, which promote carbon capture in the offseason. Higher levels of organic matter in soils can lead to increased crop productivity and quality, as well as improve soil drainage.

Working with Farmers to Achieve Agricultural Adaptation and Mitigation

Climate and agricultural researchers have developed a strong foundation for understanding adaptation and mitigation practices that can help farmers manage climate change but understanding the science behind adaptation and mitigation is not enough; farmers have to be willing to adopt new management strategies. Encouraging adaptation and mitigation practices is a challenging endeavor. While there is a comprehensive body of research that looks at public understanding of climate change and sustainable behavior, very little has been written about farmers specifically (Arbuckle et al., 2013; Stuart et al., 2014). In the United States, comprehensive climate change legislation has lacked widespread political support and as a result agricultural adaptation and mitigation remains mostly a voluntary process. The fields of sociology, psychology, communication, policy and planning, and economics all have an important role to play in helping us understand the social, political, and policy-related dimensions of climate change. However, since this case study is focused on the role of conservation practitioners in achieving the adoption of adaptation and mitigation strategies, our focus will not be on top-down regulatory approaches to climate change but on the role of practitioners in encouraging and facilitating voluntary best management practices among farmers.

Research on the beliefs, attitudes, and behaviors of farmers with regard to climate change has shown that most farmers have a limited understanding of the science of climate change, are overwhelming opposed to regulatory approaches to managing climate change, and are unlikely to voluntarily adopt GHG mitigation practices (Arbuckle et al., 2013; Niles et al., 2013; Stuart et al., 2014). The reasons why farmers have generally been unwilling to respond to climate change have been understudied, but we can draw valuable insights from the small body of work on the issue from the disciplines of communication and social psychology. To begin with, one of the key attributes of successful science communication efforts is that scientific information needs to be articulated in socially relevant ways for a targeted audience. Nisbet and Scheufele (2009) argue that scientific communication needs to be based on the idea that:

> Science literacy has only a limited role in shaping public perceptions and decisions. […] any science communication efforts need to be based on a systematic empirical understanding of an intended audience's existing values, knowledge, and attitudes, their interpersonal and social contexts, and their preferred media sources and communication channels. (p. 1767)

Just as it is for the general public, understanding the values and perceptions of farmers is critical for climate science education aimed at encouraging behavior change. However, practitioners must also recognize that encouraging behavior change is not only about effective communication but that there may be concrete cultural and economic barriers that can make it difficult for farmers who would like to change their practices to do so.

Promoting Climate Change Literacy and Sustainable Behavior

The American public, and farmers in particular, have a poor understanding of climate change science. In a study conducted among Midwestern farmers only 8% of those surveyed believed that climate change was mostly the result of anthropogenic activity (Arbuckle et al., 2013a) as compared to 46% among the U.S. public (Pew Research Center, 2013). This finding is significant because researchers have found that farmers who recognize the anthropogenic causes of climate change are more likely to express a willingness to adopt adaptation practices and are significantly more likely to adopt mitigations practices (Arbuckle et al., 2013a; Arbuckle et al., 2013b; Niles et al. 2013; Stuart et al., 2014). Some have argued that a lack of education is one reason farmers have been slow to recognize the threat of climate change and to implement meaningful adaptation and mitigation management strategies (Nisbet & Scheufele, 2009; Stuart et al., 2014). At its most basic level this could mean educating farmers about the fundamental science of climate change, such as how the greenhouse effect works and how people contribute to GHG emissions. Researchers at the University of California at Berkeley have found that providing a brief explanation of the greenhouse effect to people can have a significant influence on their willingness to accept that climate change is anthropogenic in origin (Ranney, Clark, Reinholz, & Cohen, 2012). Helping farmers understand how agriculture contributes to the greenhouse effect could potentially increase their willingness to recognize that climate change poses a risk to their farms (Safi, Smith, & Liu, 2012), and if they recognize their own contributions to GHG emissions they may be more willing to adopt mitigation practices (Arbuckle et al., 2013a; Stuart et al., 2014). A farmer's understanding of climate change has the greatest impact on whether or not they will engage in mitigating behaviors (Arbuckle et al., 2013a; Stuart et al., 2014). However, as we will discuss in more detail later, risk perceptions have the greatest impact on support for adaptation (Arbuckle et al., 2013a).

The Importance of Trust

As important as climate change education may be, it is important to recognize that scientific literacy is not always a prerequisite for public support for scientific research and public policy (Nisbet & Scheufele, 2009). When surveyed, 84% of U.S. residents saw, "science as having a mostly positive impact on society" (Masci, 2009). For some non-politicized scientific issues, such as medical research on a cure for Alzheimer's disease, scientific literacy on the issue is likely not required to develop support. However, climate change research has become politically charged, not unlike stem cell research and the theory of evolution. The political discourse surrounding climate change has infused widespread doubt among the general public about whether or not there is scientific consensus on the issue (Nisbet & Scheufele, 2009). Despite the public's uncertainty, there is almost no uncertainty among climate scientists; 97% of climate scientists agree that climate change is the result of human activities (Doran & Zimmerman, 2009). This erroneous belief in the level of uncertainty is likely a significant factor in explaining the divide between public support for science and public disbelief in climate change (Nisbet & Scheufele, 2009).

Educating the public, including farmers, about the overwhelming consensus surrounding climate change may be important for encouraging agricultural adaptation and mitigation. Practitioners may also find that some farmers, possibly those with high levels of trust in public institutions such as Cooperative Extension services, do not need to understand the science of climate change in order to express a willingness to adopt extension educators' recommendations for adaptation and mitigation (Arbuckle et al., 2013b). Cooperative Extension networks with their connection to every county within their respective states, coupled with their long history of interaction and rapport with farmers, puts them in a pivotal position for providing climate change education, as well as adaptation and mitigation outreach. However, Cooperative Extension may not always be the most trusted source of information for every farmer. Many farmers may be more likely to trust recommendations from within the agricultural industry, such as those from fertilizer companies (Arbuckle, 2013b; Stuart et al., 2014). Furthermore, as noted by Arbuckle (2013b), "farmers who express higher levels of trust in agricultural industries are less likely to believe in climate change, much less anthropogenic causes"

(p. 22). Practitioners may be better able to educate farmers with high levels of trust in agricultural industries by working closely with representatives from these agricultural industries when possible.

Adaptation and Mitigation Education

Another educational need is to inform farmers about adaptation and mitigation practices that will be beneficial to them. In a study conducted by Michigan State University on fertilizer management practices among Michigan corn farmers, researchers found that most farmers were unaware of reduction methods that were available to them, in part because Michigan State Cooperative Extension had taken the position that discussing climate change might alienate extension agents from the farmers with whom they were working (Stuart et al., 2014). Simply put, farmers cannot be expected to adopt voluntary adaptation and mitigation measures if they are unaware of them and if educators are reluctant to discuss them as part of their outreach efforts.

As important as providing farmers with educational information is, reliance on the educational deficit model is not enough to successfully encourage adaptation and mitigation behaviors (Nisbet & Scheufele, 2009). Although they represented only a small portion of the study by Michigan State, even corn farmers who were aware of available nitrogen mitigation strategies were not using them (Stuart, et al., 2014). These findings expose the limits of the educational deficit model in accomplishing behavior change. Education on an issue does not guarantee behavior change; behavior change may be connected to a complex system of beliefs, attitudes, emotions, norms, and economic incentives (Nisbet & Scheufele, 2009).

Understanding Risk Perceptions

Researchers have found that farmers who perceive climate change as posing a risk to their farms are significantly more likely to support adaptation efforts and to a slightly lesser extent support mitigation efforts (Arbuckle et al., 2013a; Arbuckle et al., 2013b). When educating farmers about the risks of climate change it is likely important to connect experiences that are relevant to their geographic area to climate change, such as drought in the southwest or extreme heat in the northeast (Niles et al., 2013). A study conducted among rural landowners in Nevada, which included farmers and ranchers, found that you cannot assume that even when people are experiencing the direct effects of climate change that they will associate those effects (e.g., drought, frost, flooding) with the phenomena (Safi et al., 2012). Extreme heat and drought in Nevada had no observable effect on rural landowners' perception of the risk of climate change (Safi et al. 2012). However, Safi et al. (2012) did find that "being [politically] conservative significantly decreases risk perception" (pg. 1055). This finding echoes the point that climate change has become politically charged. In recent history, farmers have shown strong support for conservative political candidates (Stephenson, 2012). Conservative political affiliation is closely tied to a disbelief in the existence of climate change, and an even stronger disbelief that climate change is occurring as a result of anthropogenic activity (Pew Research Center, 2013). The influence of politics on risk perception and climate change beliefs is one barrier that may be difficult for conservation practitioners to overcome.

As noted earlier, mitigation support is not predicated upon one's perception of risk but is most influenced by one's climate change beliefs, particularly whether or not one believes its cause is anthropogenic. This is an important finding because it speaks to the point made by Nisbet and Schufele (2009) regarding developing outreach efforts that are tailored to specific contexts and audiences. There is no single strategy that will work for all farmers; climate change education on adaptation may have to be distinctly different from climate change education on mitigation (Arbuckle et al., 2013b). Concurrently, Arbuckle (2013a) has also found that climate change beliefs have an impact on perceptions of risk: "farmers who believe climate change is occurring and associated with human activity expressed substantially higher levels of concern" (p. 20). These findings suggest that coupling education on the science of climate change with messages regarding the risks of climate change may be particularly valuable.

Economic Barriers

While communicative barriers represent a fundamental concern for encouraging the adoption of adaptation and mitigation practices, farmers may be faced with economic obstacles as well. Such barriers include a lack of capital for investment in new technologies and procedures. Many farms operate with very small profit margins and agricultural markets can be volatile, in part because yearly crop yields can be difficult to predict. This uncertainty is likely to factor into a farmer's perception of the risks involved with financial investment. For small farms the risks may be even greater because they are likely to operate on even tighter profit margins and are less able to absorb the fallout of less productive years. Farmers with relatively small acreages may also have greater difficulties getting credit for investment (Stuart et al., 2014). Furthermore, credit lending may be tied to yield requirements, not necessarily increased production efficiency. For example, an anaerobic digester may make sense from a mitigation and energy savings perspective, but it does not mean an increase in dairy production and therefore may not be eligible for certain types of loans. An emphasis on yield over efficiency may encourage practices such as the heavy application of nitrogen fertilizer, which runs counter to strategies designed to mitigate N_2O emissions. Crop insurance may also be predicated on yield levels, which could encourage similar behaviors.

In a study conducted with Michigan corn seed farmers, researchers learned that many of these farmers' contracts with seed companies were also dependent upon yield levels (Stuart et al., 2014). As a result of these contracts, farmers perceived the risk of changing their practices as too great because if their yield levels dropped they could lose their contracts. These kinds of economic arrangements discourage adaptation and mitigation in agriculture, but may be difficult to overcome without government regulation or government incentives for the adoption of new best practices. Barriers to widespread adoption involve communication efforts on the behalf of researchers and educators, but also very concrete economic barriers for farmers, which are deeply connected to a farmer's perceptions of risk.

Beliefs and Attitudes Toward Regulation

Farmers have shown a strong aversion to agricultural regulations of GHGs (Arbuckle et al., 2013b; Niles et al., 2013). This same sentiment can be seen in the position of the American Farm Bureau Federation, arguably the most powerful farm lobby in the United States. The Farm Bureau "does not support any actions or policy that federal agencies could adopt, or the utilization of any existing authority, to regulate emissions of GHGs" (American Farm Bureau Federation [AFBF], 2013). Despite the Farm Bureau's opposition to GHG emission regulations they do support federal funding for agricultural adaptation to climate change (AFBF, 2013). The Farm Bureau's support for adaptation is in alignment with research that shows significantly greater support among farmers for adaptation than mitigation practices (Arbuckle et al., 2013a; Niles et al., 2013). One possible explanation for why farmers have expressed a greater interest in adaptation than mitigation is that adapting to changing or unexpected agricultural conditions have long been a requirement of successful farming (Nowak, 2013). While adaptation has likely been a part of agriculture for generations, mitigation is a relatively new concept that is typically discussed in terms of climate change regulation (USDA, 2012; Arbuckle et al., 2013b). One explanation for farmers' opposition to top-down regulatory approaches is that farmers past experiences with environmental regulation have been shown to have a long-lasting negative impact on their willingness to support climate change regulations (Niles et al., 2013). Furthermore, Niles et al. (2013) found that farmers were more likely to perceive a greater risk to their farms from climate change regulation than from climate change itself. One promising finding from Niles et al. (2013) was that farmers past experiences with regulatory measures did not discourage support for government programs that encouraged voluntary approaches to managing climate change.

Farmers' aversion to climate change policy may in part be because they have felt excluded from the process of regulatory decision-making (Lind & Tyler, 1988; Smith & McDonough, 2001). Farmers represent a small portion of U.S. citizens but the policy decisions that impact their daily lives are be made by a much wider public electorate. As the American population becomes increasingly urbanized, farmers may see their values, experiences, and interests as distinctly different from urban and suburban residents. Research has shown that even the majority of farmers who perceive a high degree of risk from climate change do not favor regulatory approaches (Arbuckle, et al. 2013b). The public's low prioritization of environmental issues coupled with the opposition of farmers to regulatory measures reaffirms the importance of the role conservation educators will play in encouraging the voluntary adoption of agricultural adaptation and mitigation methods. When communicating with farmers it may be important for practitioners to avoid language that could trigger regulatory associations and negative responses to adaptation and mitigation.

Articulating Win-Win Scenarios

For those who do not work in the agricultural economy it can be easy to romanticize agrarian life, but to farmers, farming is a business. When adopting new practices farmers want to know how much it will cost them, how much time it will it take to implement, and what the returns will be. As a result, when communicating with farmers it may be important to address all of these concerns and to do so in a way that emphasizes new opportunities, as opposed to overwhelming obstacles. Earlier efforts to communicate with the public about climate change often utilized an alarm framework, which emphasized impending climate catastrophe (Nisbet & Scheufele, 2009). An example of this kind of framing can be found in the film *An Inconvenient Truth*. Critics of the alarm framework have argued that an emphasis on worst-case scenarios can make behavior changes appear futile and can undermine the legitimacy of more modest expectations for climate change (Nisbet & Scheufele, 2009). The existing research has shown the importance of communicating climate change risk, however this information likely needs to be coupled with information about opportunities for overcoming those risks.

Several researchers have argued that one way to emphasize opportunity is to move away from "sounding the alarm" and employing an economic framework that emphasizes a return on investment (Arbuckle et al. 2013b; Niles et al. 2013; Stuart et al. 2014). Many agricultural activities, as outlined earlier (e.g. conservation tillage), can promote profitability as well as climate change mitigation and adaptation. These kinds of practices can be described as a win-win because they can improve resilience, mitigate GHGs, and increase the profitability of farms. An emphasis on economic incentives may work for some farmers but not necessarily all farmers. Andrews et al. (2013) found that the use of an economic framework to educate farmers on conservation tillage practices had no effect on the attitudes, beliefs, and behaviors of farmers when compared to other educational alternatives. The reason for this was likely because farmers in the study had already made up their minds about the tillage practices they were interested in using and what the effects would be (Andrews et al. 2013). However, practices that are entirely new to farmers or that don't appeal to any particular set of existing values, such as the use of renewable energy sources on their farms, may be best communicated through an emphasis on economic incentives. An economic framework may be an effective communication strategy in some instances, but critics have argued that once the financial incentives for adaptation and mitigation diminish, without a belief in the value of sustainable agriculture, broader public support for climate change policy may not be possible (Ockwell et al., 2009; Niles et al., 2013).

Communicating the importance of climate change to farmers may require the use of multiple frameworks that include financial incentives and conservation values. Conservation educators will also have to utilize a diverse set of communication channels that may include publishing articles in agricultural trade magazines, utilizing social media, and conducting individual farm visits. Not only should practitioners be knowledgeable about how to implement agricultural best management practices, but they should also be flexible in how they communicate that information. Conservation practitioners will likely have to draw upon their personal connections and experiences in order to tailor educational information to the needs of farmers across scales. Some outreach strategies may be effective when utilized in certain regions, or communities, while other strategies for encouraging behavior change may have to be developed at the level of the individual farmer (Niles et al., 2013).

Conclusion

Climate change poses an unprecedented challenge to agriculture throughout the world. In Northeastern states, such as New York, these challenges will include warming temperatures, increased weather variability and heavy precipitation events. These climatic changes will require farmers to utilize new adaptation strategies in order to preserve the viability of their farms. These strategies will have to be multifaceted and will likely include the planting of new crops and varieties, the use of conservation tillage, and the use of new technologies such as improved irrigation and drainage systems among others. In addition to adopting new agricultural practices farmers will have to begin mitigating greenhouse gas emissions if we hope to minimize the impact of climate change on global and regional scales. Many of these mitigation efforts will be win-win scenarios that help farmers adapt to a changing climate while leading to reductions in agriculture's carbon footprint. Given a current lack of political support for comprehensive climate change legislation many of these adaptation and mitigation strategies will likely require voluntary adoption by farmers. Working with farmers to achieve adaptation and mitigation is a difficult challenge but one that Cooperative Extension Services, if given enough institutional support are well suited for. When communicating with farmers about climate change understanding the importance of educational awareness, risk perception, economic circumstances, trust and political beliefs will be important. Climate change is a complex issue that requires collaboration between academics, farmers, policy makers, businesses and citizens. The consequences of inaction may be severe but the opportunities for action are already taking place or within reach.

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