Mike Castellano, Ph.D.
Professor of Agronomy
Iowa State University, Ames, Iowa

Written Testimony to the United States Senate Committee on the Budget
Hearing on:
Droughts, Dollars, and Decisions: Water Scarcity in a Changing Climate
Wednesday 22 May 2024

Climate change is a serious risk. We must take steps to mitigate and adapt to climate change without causing economic retreat or slowing of progress towards improving the human condition, much of which is attributable to agriculture. Dozens of agronomic practices have been suggested to mitigate greenhouse gas emissions and adapt to a changing climate. The best practices focus on improving nitrogen management because nitrogen – not carbon – accounts for more than 50% of emissions from agriculture and us much as 70% of emissions from crop production.

Herein, I highlight two of these practices: **agricultural drainage** and **crop residue management**. These practices are among the most effective for climate change adaptation and mitigation because they increase yield, improve nitrogen use efficiency, and enhance the performance of other conservation practices such as reduced tillage and cover crops. Unfortunately, many of these benefits are poorly known and, as a result, these practices are generally overlooked by conservation programs despite their positive effects on productivity and environmental performance. Farmers understand the yield benefits of these practices but better communication of the environmental benefits would ensure that farmers understand and act on them, especially the reductions in nitrogen fertilizer. Education, assistance, and incentive programs would promote the success of these practices.

In summary, we cannot – and need not – sacrifice agricultural productivity for climate change mitigation. In this context, I have three key messages:

1. **Water excess reduces crop yields with similar magnitude as water scarcity**. Variability in the timing and magnitude of precipitation is a major concern, but this variability can be managed to benefit crop yield and environmental outcomes (see #3).

2. Agricultural sector greenhouse gas emissions are among the hardest to abate. Unlike other sectors, **most agricultural emissions are not from fossil fuels**. Nitrous oxide, a byproduct of soil biological processes that are critical to plant growth, accounts for more than 50% of emissions from crop production. Water and nitrogen inputs drive nitrous oxide emissions; effective water and nitrogen management will reduce emissions.

3. Although agricultural sector emissions are hard to abate, the most effective mitigation and adaptation practices **increase yield and reduce greenhouse gas emissions**. These practices make reductions in agricultural emissions a real possibility because they link productivity to

environmental performance. Two practices with significant potential include agricultural drainage (including coupled drainage-irrigation recycling) and crop residue management (the partial harvest of non-grain portions of a crop). Both practices increase crop yields while reducing nitrogen fertilizer needs and nitrous oxide emissions. They do this in part by improved water management. Moreover, **the potential to sustainably harvest a portion of crop residues is growing every year, representing a new source of feed, fiber, and fuel, that can help to decarbonize other sectors of our economy**.

<u>Expansion on Key Messages:</u>

1. Water excess reduces crop yields with similar magnitude as water scarcity.

The primary climate-related challenge for farmers is managing year-to-year variability in the amount and timing of precipitation and greater frequency of extreme precipitation events[1]. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) indicates "high confidence in observed increases in extreme precipitation events (including hourly totals) in Central and Eastern North America" and "high precipitation is projected to increase across North America (high confidence) except for portions of Western North America where projections are mixed (medium confidence of increase)"; in contrast, the AR6 "found limited evidence for broadly observed changes in North American agricultural and ecological drought"[2].

These changes in extreme precipitation can negatively impact crop production in several ways. Excess water has negative effects on plant growth and physiology. Saturated soils limit plant respiration and root growth. Reduced root growth limits water and nutrient uptake while increasing the risk of lodging (i.e., stem breakage). Reduced plant growth and nutrient uptake, especially when coupled with excess water, can increase environmental losses of fertilizers. Lack of sufficient soil drainage increases yield variability, reduces profitability, and increases greenhouse gas emissions[3].

In addition to negative effects on plant growth, excess water limits field trafficability and the effectiveness of conservation practices such as cover crops, reduced tillage, and precision nitrogen fertilizer management. Management of cover crops and precision nitrogen fertilizer applications require extra field trafficking; excess water increases risk that this operation is delayed, which can delay the planting of primary crops. Reduced tillage can also reduce field trafficability by slowing soil drying, at least in initial years of implementation. Late planting of crops reduces yield potential. Excess water reduces US corn yield by 34% on average whereas drought reduces US corn yield by 37% on average[4]. In years of excess water, intense rainfall

[1] USGCRP, 2023: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023

[2] Ranasinghe, R., et al. "Climate Change Information for Regional Impact and for Risk Assessment". In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change pp. 1767–1926, doi:10.1017/9781009157896.014.

[3] Castellano, M.J., et al. *Nature Sustainability* 2.10 (2019): 914-921.

[4] Li, Y., et al. "Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States." *Global change biology* 25.7 (2019): 2325-2337.

reduces soybean yield more than does the same amount of precipitation more evenly distributed across the growing season[5].

2. Agricultural sector greenhouse gas emissions are among the most difficult to abate.

Unlike other sectors, most agricultural emissions are not from fossil fuel combustion. Instead, they are byproducts of biological processes that are critical to food production. These include methane emissions from livestock production, manure management, and rice cultivation as well as nitrous oxide emissions from soil and manure management. According to US EPA, agriculture accounts for approximately 10% of total US emissions, and **more than 50% of agricultural emissions are from nitrous oxide[6] (Figure 1)**.

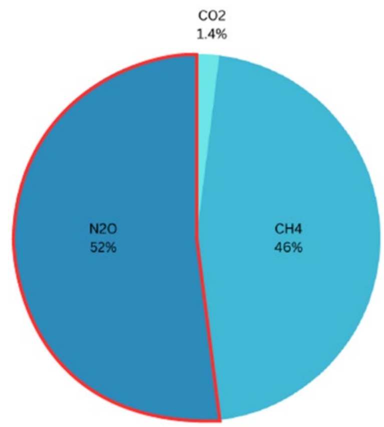


Figure 1 (right): Sources of US agriculture sector emissions (US EPA, 2024[6]). Nitrous oxide (N2O) accounts for 52% of emissions and methane (CH4) accounts for 46% of emissions. Note: EPA does not include on-farm energy use in the agriculture sector, but it is a relatively small contributor to emissions (see Figure 3).

As a proportion of total US emissions, agricultural emissions are expected to increase rapidly over the coming decades as other sectors implement ready decarbonization strategies such as biofuels, wind, and nuclear. Consistent with this expectation, **since 1990, agricultural emissions have grown more than any other sector (7.7%) while emissions from energy decreased by 3.4% over the same time[6]**. Similarly, comparison of emissions between Iowa and the US offers a look into the future: In Iowa, agriculture recently surpassed energy to become the largest sector of emissions as the energy sector was decarbonized with wind. A recent White House report also expects non-CO2 emissions, largely from agriculture, to become the largest source of US emissions by 2050[7].

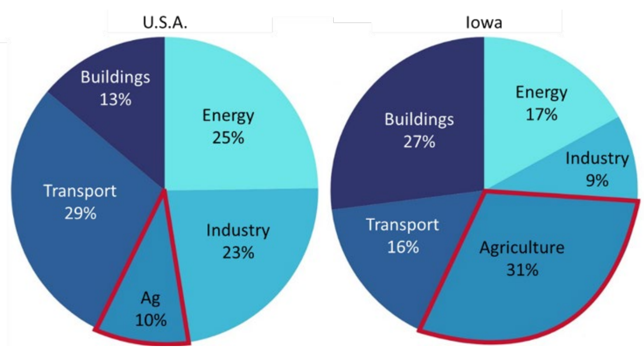


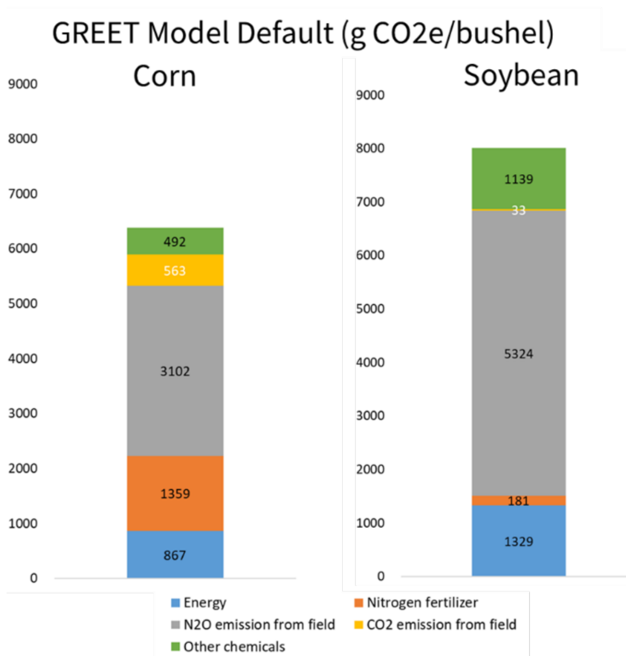
Figure 2 (right): Greenhouse gas emissions by sector for the USA (US EPA, 2024[6]) and Iowa. Agriculture emphasized in red. Agriculture accounts for 10% of US emissions and 31% of Iowa emissions. Notably, Iowa emissions are dominated by agriculture for two reasons: 1) agriculture is a large sector, and 2) Iowa is a leader in per capita wind installation.

---

[5] Pasley, H.R., et al. "Modeling flood-induced stress in soybeans." *Frontiers in Plant Science* 11 (2020): 501063.
[6] Table ES-3, EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004.
[7] The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050. Published by the United States Department of State and the United States Executive Office of the President, Washington DC. November 2021.

Notably, US EPA and state-level accounting does not include emissions from on-farm energy use or fertilizer production in estimates of agricultural sector emissions. However, the US Department of Energy GREET Life Cycle model[8] does include these emissions in estimates for the production of biofuel feedstocks (i.e., emissions per bushel of production). According to the GREET model, 70% of emissions from corn production are attributable to nitrogen: of those, approximately 50% is attributable to nitrous oxide from soil management and approximately 20% to nitrogen fertilizer production. These sources of emissions are linked because the amount of nitrogen fertilizer input and soil moisture are the major controls on nitrous oxide emissions. Nevertheless, emissions from crops that do not typically receive nitrogen fertilizer inputs are also dominated by nitrous oxide from soil management. Approximately 67% of emissions from soybean production are attributable to nitrous oxide emissions from soil management. On-farm energy use represents less than 20% of emissions from these crops (Figure 3).

Figure 3 (right): US Department of Energy GREET model Feedstock Carbon Intensity Calculator default outputs for the average emissions of the US corn and soybean crops. Units are grams of carbon dioxide equivalent (CO2e) per bushel. Nitrogen related emissions are from nitrous oxide (grey) and nitrogen fertilizer synthesis (orange). In total, nitrogen-related emissions account for 70% of emissions from corn and 69% of emissions from soybean. Field-scale accounting is critical to credit locations and management systems with the lowest carbon intensity scores.



Although agricultural emissions are hard to abate, there are serious opportunities to reduce agricultural emissions because the best opportunities also increase crop yield and reduce the need for costly inputs such as nitrogen fertilizer. Strategies that focus on nitrogen use efficiency are needed[9] and water management is one of the best ways to improve nitrogen use efficiency[3,10]. Soil carbon sequestration has been proposed as a way to offset non-CO2 agricultural emissions and it should be employed where possible. However, the capacity for soil carbon sequestration is finite and it cannot offset the recurring emissions from nitrous oxide[11]. Together, these realities

[8] https://greet.anl.gov/tool_fd_cic
[9] Schlesinger, W. H. (2022). Biogeochemical constraints on climate change mitigation through regenerative farming. *Biogeochemistry*, *161*(1), 9-17.
[10] Quemada, M., & Gabriel, J. L. (2016). Approaches for increasing nitrogen and water use efficiency simultaneously. *Global Food Security*, *9*, 29-35.
[11] Lawrence L.C. et al. "Nitrous oxide emissions from agricultural soils challenge climate sustainability in the US Corn Belt." *Proceedings of the National Academy of Sciences* 118.46 (2021): e2112108118.

emphasize the need for conservation practices that aim to maximize yield while reducing nitrogen fertilizer needs.

3. Agricultural drainage and crop residue management: a systems approach for climate change mitigation and adaptation.

As described above, the primary climate-related challenge for farmers is managing year-to-year variability in the amount and timing of precipitation. Not only do greater precipitation extremes create challenges for crop production, but they also promote environmental nitrogen losses to nitrous oxide, the primary source of greenhouse gas emissions from crop production. Hence, coupled management of water and nitrogen are critical for adaptation and mitigation.

Agricultural drainage and crop residue management are among the very best strategies for climate change adaptation and mitigation because they improve water and nitrogen management for the benefit of productivity and environmental performance when managed with a systems approach (Figure 4). Both practices reduce the risk of waterlogging. As a result, and very importantly, both strategies significantly improve the performance of better known, more widely accepted conservation practices such as reduced tillage, cover crops, and precision nitrogen fertilizer management. This is a critical aspect of agricultural drainage and crop residue management because, on average, reduce tillage and cover crops reduce yields of corn and soybeans[12,13].

There is growing interest in crop residue harvest for a variety of applications including the production of biofuels. However, these nascent industries – and the corn and soybean farmers who grow the residues – are not receiving credit for the benefits of crop residue management including appropriate reductions in carbon intensity scoring. This is partly the result of a lack of field scale accounting. Moreover, a lack of best management practices in policy and practice for crop residue management are costing farmers due to the conventional – yet incorrect– view that residue retention is universally good. Education and technical assistance programs can help farmers to best manage drainage and crop residue management as part of a system that reduces nitrogen fertilizer needs and nitrous oxide emissions while increasing yield as well as the effectiveness of reduced tillage, cover crops, and precision nitrogen fertilizer management. Incentives can help farmers to trial these practices.

Agricultural drainage:

The US subsurface agricultural drainage infrastructure can be valued at **more than $50 billion**[14]. In a limited sample of drainage districts of the eastern US alone, drainage has been valued at

---

[12] Pittelkow, Cameron M., et al. "When does no-till yield more? A global meta-analysis." *Field crops research* 183 (2015): 156-168.
[13] Deines, Jillian M., et al. "Recent cover crop adoption is associated with small maize and soybean yield losses in the United States." *Global change biology* 29.3 (2023): 794-807.
[14] If we assume $1,000 per acre replacement cost and 50 million acres of drained land.

approximately $17 billion[15]. However, like many other pieces of US infrastructure, our drainage infrastructure is deteriorating and insufficient for current cropping systems and precipitation patterns. Much of the US drainage infrastructure was installed more than 100 years ago at a cost born almost entirely by farmers[16]. Significant upgrades are necessary.

Effective drainage systems reduce nitrogen fertilizer needs while increasing yield because they improve soil health. As a result, drainage reduces nitrous oxide emissions for two reasons: it reduces soil moisture content and the need for nitrogen fertilizer. More specifically, drainage reduces carbon intensity scores of crop production by increasing yield and reducing emissions.

Drainage can harm water quality when poorly managed and USDA policies create significant challenges to upgrading drainage systems. However, drainage systems enable "edge-of-field" water treatment practices such as denitrification wetlands and saturated buffers that are among the most effective practices for reducing nutrient runoff. These practices are far more effective than nitrogen fertilizer management and slightly more effective than cover crops[17]. Moreover, they replace relatively low-yielding areas of the landscape, increasing biodiversity.

Crop Residue Management

The annual **per-acre production of corn residues has doubled** over the last 50 years and continues to increase by approximately 100 pounds per acre per year. This increase in production offers a new resource to meet demands for food, fuel, and fiber. In the northern Corn Belt, corn residue production can exceed 5 tons per acre.

For millennia, farmers have known that removing crop residues benefits productivity of the following crop. However, until recently, harvesting of crop residues was unsustainable. Crop residue retention was required to minimize soil erosion and maintain soil organic matter. Unfortunately, this outdated perspective still drives policy and decision making.

In the early 2000s, the USDA Agricultural Research Service initiated the Renewable Energy Assessment Project (REAP) to determine capacity for sustainable harvest of crop residues. Across 239 site-years spanning the entire US Corn Belt, the USDA REAP team found that corn residue harvest led to a 3% average yield increase in the subsequent corn crop; however, at the 45 site-years from central Iowa included in this study, the average yield increase was 8%[18]; benefits of residue harvest tend to be greater in wetter environments such as central Iowa. At the same time, residue harvest reduces the nitrogen required to produce the following crop because it improves soil health.

Researchers from the University of Minnesota, University of Illinois, and Iowa State University have demonstrated that corn residue harvest decreases the optimum nitrogen input while

---

[15] Edwards, Eric C., and Walter N. Thurman. "The economics of climatic adaptation: agricultural Drainage in the United States." *Proceedings of the NBER/USDA Conference on Economic Perspectives on Water Resources, Climate Change, and Agricultural Sustainability*. 2022.

[16] "Paying $307,000,000 for Iowa Drainage" *New York Times*, September 23, 1910.

[17] Reducing Nutrient Loss: Science Shows What Works Iowa State University, 2019.

[18] Karlen, D. L., & Johnson, J. M. (2014). Crop residue considerations for sustainable bioenergy feedstock supplies. *BioEnergy Research*, *7*(2), 465-467.

increasing yield of the following corn crop[19]. The reduction can be more than 20%. As a result, nitrous oxide emissions decline significantly.

In addition, the USDA REAP project demonstrated that residue harvest, on average, reduced nitrous oxide emissions by 7% even without considering the role of reduced nitrogen fertilizer inputs (i.e., nitrous oxide emissions were compared in paired fields with and without residue harvest, but the same nitrogen fertilizer input)[20]. Moreover, consistent with the important effect of soil moisture on nitrous oxide emissions, the reduction increased with average growing season precipitation; in the wetter parts of the Corn Belt, the reduction was as much as 15%. A 7-15% reduction in nitrous oxide may seem small, but the global warming potential of nitrous oxide is high: one pound of nitrous oxide emissions is equivalent to approximately 290 pounds of carbon dioxide emissions.

The benefits of crop residue harvest on greenhouse gas emissions are not limited to corn. Rice residue removal can reduce methane emissions by more than 50%[21]. Residue management in rice can also reduce nitrogen-related emissions in a similar way to corn residue management[22].

There is also evidence that suggests corn residue harvest can improve water quality outcomes. Residue harvest is well known to increase evaporation[23]. Reductions in evaporation reduce drainage, and the volume of drainage, rather than the concentration of nitrate, is the primary control on the amount of nitrate losses to waterways. Reductions in nitrogen fertilizer input would lead to further improvements in water quality.

The potential benefits of crop residue management to farmers are large and growing. Rational residue harvest also provides a new crop that can generate economic activity and help to decarbonize other hard-to-abate sectors. However, there is significant inertia behind the perspective that complete residue retention is the best management practice. The latest research demonstrates that partial residue harvest can mitigate greenhouse gas emissions and increase yield while maintaining soil health. A final salient finding of the USDA REAP project was that soil organic matter does not decline with partial residue harvest, likely because potential losses are offset by the year-over-year increase in crop residue production[24]. Education, assistance and incentive programs can help realize the benefits of rational residue harvest.

---

[19] Coulter, J. A., & Nafziger, E. D. (2008). *Agronomy Journal*, *100*(6), 1774-1780; Pantoja, et al. (2015). *Soil Science Society of America Journal*, *79*(4), 1249-1260; Sindelar, A. J. et al (2013). *Agronomy Journal*, *105*(6), 1498-1506.

[20] Jin, V. L., et al (2014). Soil greenhouse gas emissions in response to corn stover removal and tillage management across the US Corn Belt. *BioEnergy Research*, *7*(2), 517-527.

[21] Linquist, et al. "Greenhouse gas emissions and management practices that affect emissions in US rice systems." *Journal of environmental quality* 47.3 (2018): 395-409.

[22] Qian, Haoyu, et al. "Greenhouse gas emissions and mitigation in rice agriculture." *Nature Reviews Earth & Environment* 4.10 (2023): 716-732.

[23] Flerchinger, G. N., Sauer, T. J., & Aiken, R. A. (2003). Effects of crop residue cover and architecture on heat and water transfer at the soil surface. *Geoderma*, *116*(1-2), 217-233.

[24] Nunes, Marcio R., et al. "Science-based maize stover removal can be sustainable." *Agronomy Journal* 113.4 (2021): 3178-3192.

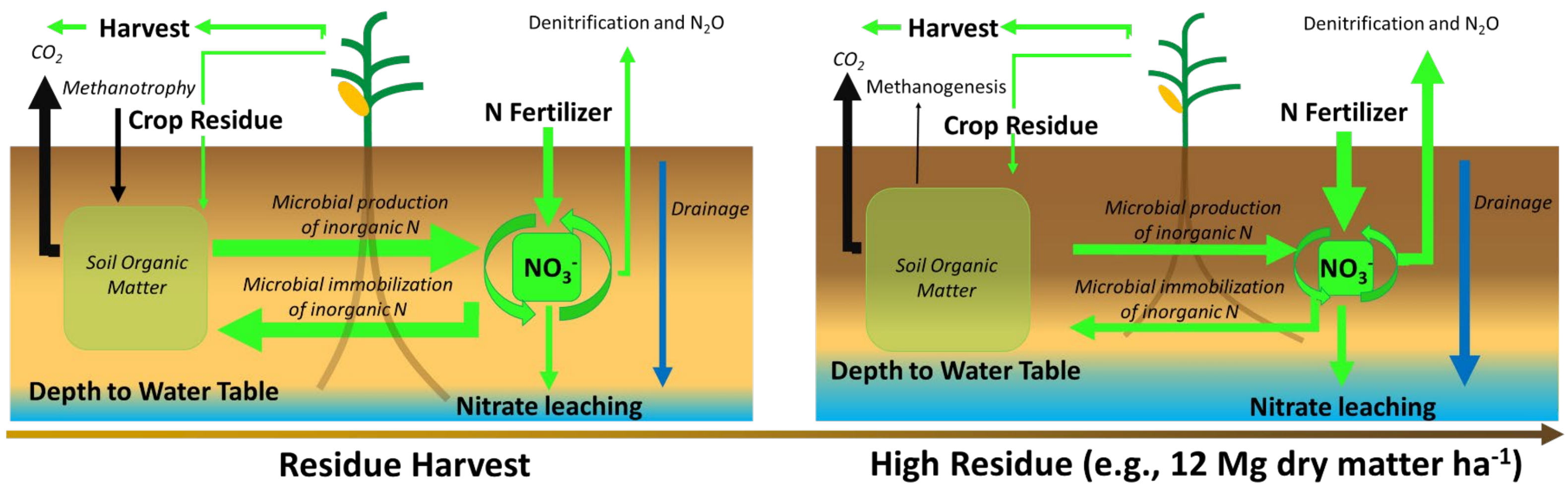


Figure 4 (above): Conceptual understanding of the biophysical benefits of crop residue management on crop production and the environment. Crop residue harvest warms and dries the soil, promoting faster internal soil nitrogen cycling and faster, deeper root growth. As a result, the system is less reliant on external nitrogen fertilizer inputs, crop yield is higher, and environmental losses to nutrient runoff and nitrous oxide emissions are lower.