Putting Carbon into Soil

Tilled

Improving Soil Health and Capturing CO_2

Adapting Agriculture to Climate Change — an Immediate First Step

Drs. Deb O'Dell & Neal Eash

No-till

Real. Life. Solutions.™

UTIA INSTITUTE OF AGRICULTURE THE UNIVERSITY OF TENNESSEE

The current situation

- **Fertilizers provide Farmers economic sustainability, but at a cost to the Soil and Environment**
  - Fertilizers can maintain profitable production
  - But, they also mask degraded soils

Photo courtesy of USDA NRCS

"It was only when we stopped using fertilizer that we realized something bad was happening to our soils."

1997 quote from Malawi farmers surveyed during early stages of Conservation Agriculture

(Evans et al., 1999 and Bot and Benites, 2001)

USDA programs already provide education, technical assistance, and applied research to make sustainable practices work for farmers

- USDA-ARS
  (Agricultural Research Service)
- USDA-NRCS
  - EQIP (Environmental Quality Incentives Program)
  - CRP (Conservation Reserve Program)
  - CSP (Conservation Stewardship Program)
  - CEAP (Conservation Effects Assessment Project)

Photo courtesy of USDA NRCS

- Supporting farmers in applying best practices that improve agricultural operations, sustainability, and soil conservation
- "Sustainable Soils" substitutes for Sustainable Agriculture

The problem is complex USDA acknowledges this

- Multiple factors impact Farmer choices and results:
  - Geography
  - Climate (e.g., rainfall timing and intensity)
  - Soil
  - Crops
  - Economics
  - Traditions

To ensure food security
We're going to focus on the Ag & Grassland sector

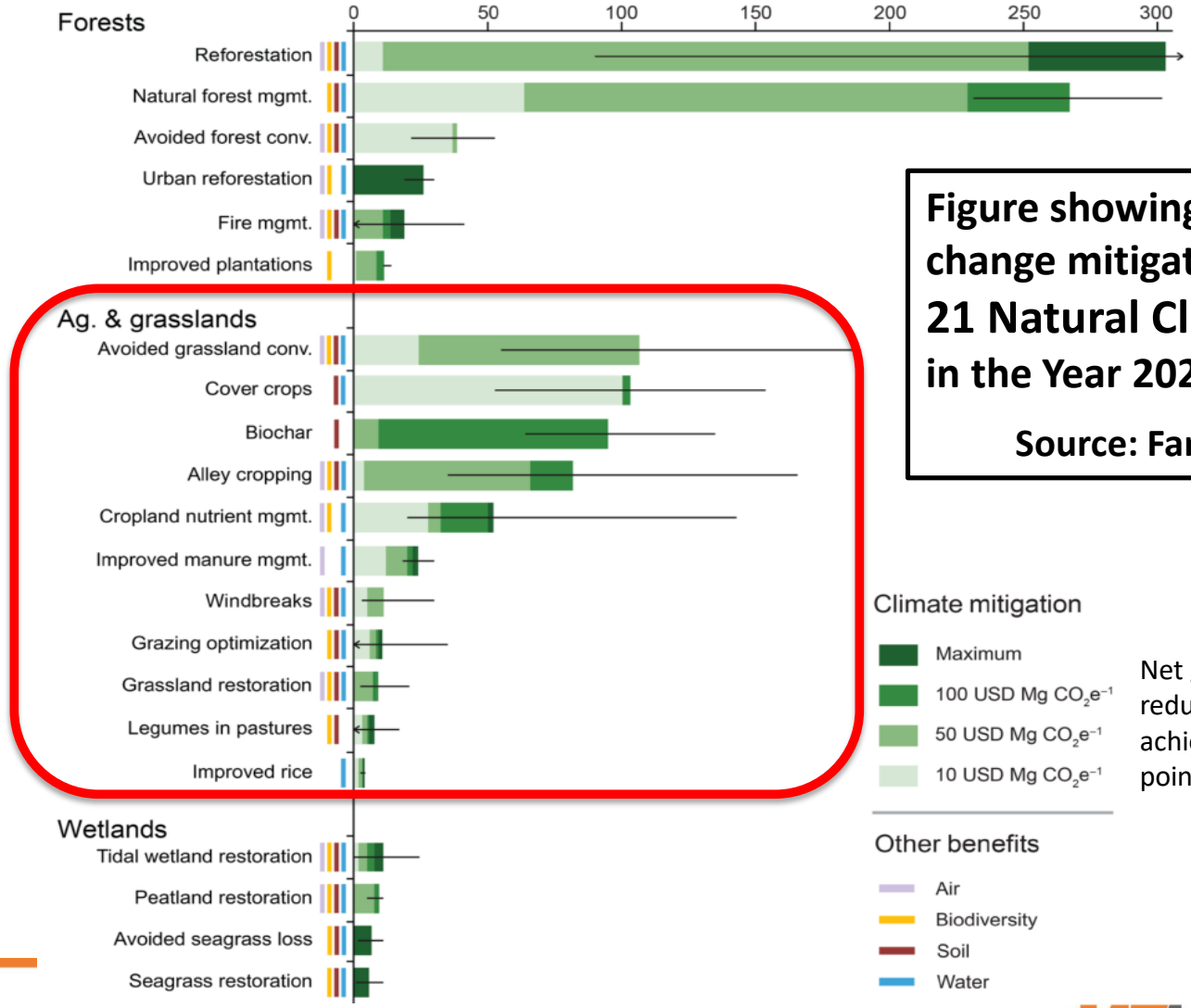


Figure showing climate change mitigation potential of 21 Natural Climate Solutions in the Year 2025 (Tg CO_2e $year^{-1}$)

Source: Fargione et al., 2018

Net greenhouse gas (GHG) reductions that can be achieved at different price points by 2025

Avoided Grassland Conversion and Cover Crops are the top Natural Climate Solutions for the Ag. & Grasslands Sector

NOTE: Though **Biochar** and **Alley Cropping** show high potential, "current adoption is negligible"

Viable solutions are known

1. **No-till**—stop tillage as much as possible
2. **Cover crops**—keep soil covered and a crop growing during the non-growing season (winter)

Cover crops combined with reduced tillage has the greatest potential to mitigate climate change

- Keep plants growing as much as possible through the year with Cover Crops (or year round/double cropping)
- Reduced fallow over winter and non-growing periods—”All Green”

Photo courtesy of Ryan Maher, Cornell University

Photo courtesy of John Goddard, University of TN

No-till is necessary to maintain C sequestration

Reduce tillage, especially no-till!

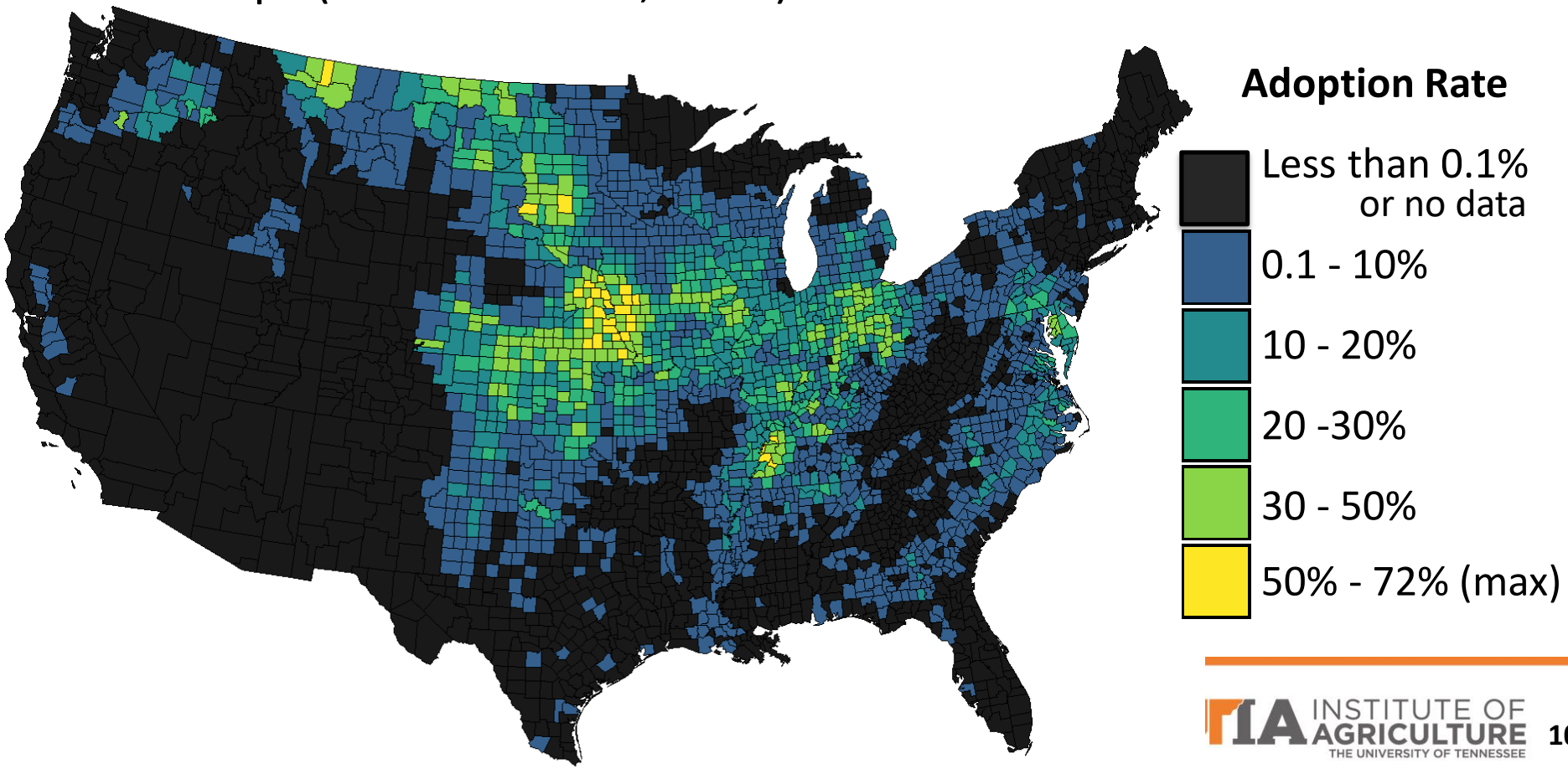
- If farmers plant a cover crop and then till it under, the potential soil carbon sequestration diminishes along with greater soil erosion and degradation, surface runoff, nutrient loss, and water pollution
- It is best to leave the cover crop to decompose on the soil surface
- Residue on the surface protects the Soil!

NO Tillage!

Plant in the Residue!

Current acceptance of no-till

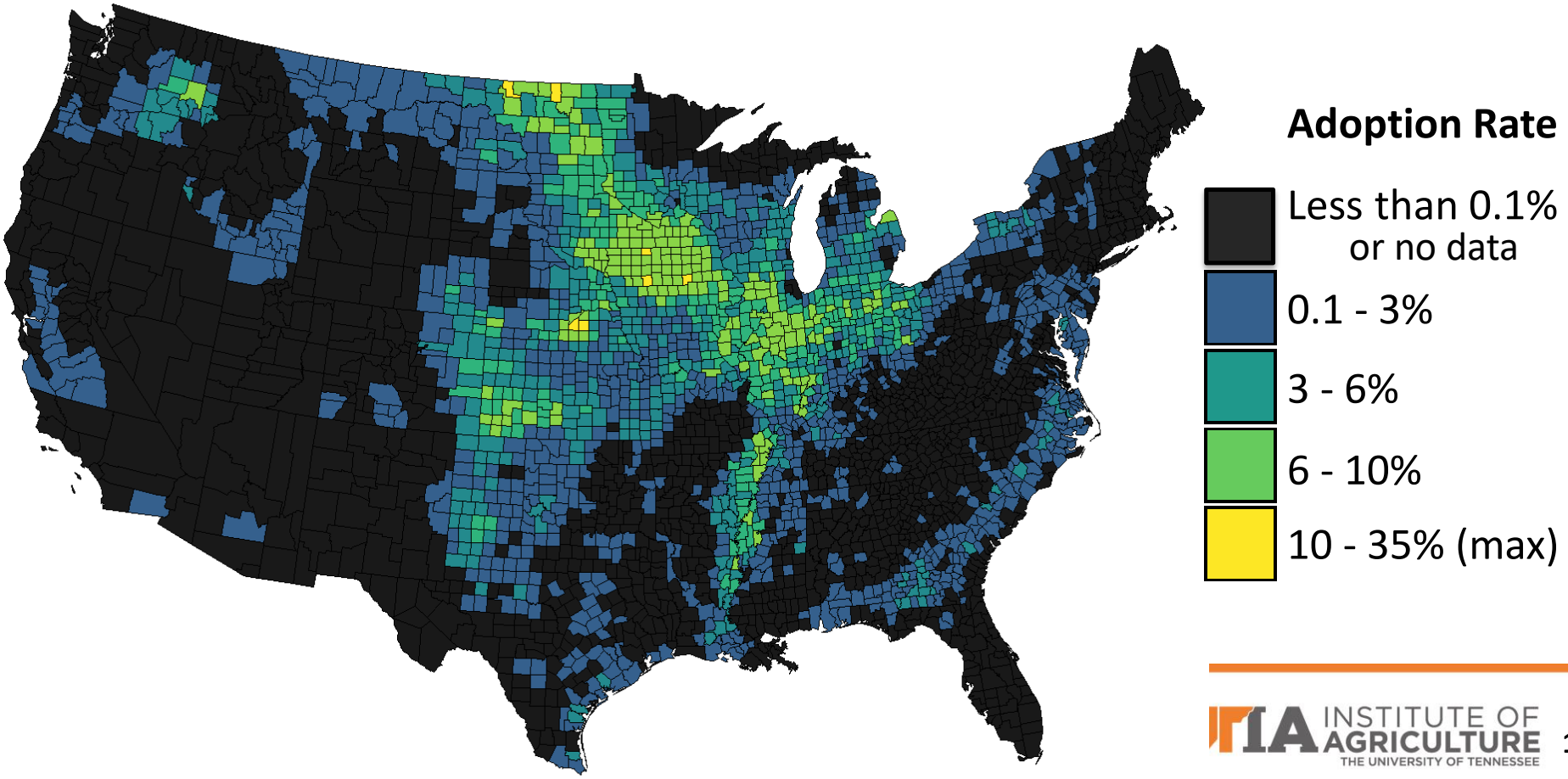
- **Many farmers have adopted no-till over the past 30 years**
  - Current U.S. adoption of no-till is approx. 21% for top 4 U.S. crops (Claassen et al., 2018)



Based on 2017 USDA census data of no-till land use practice by farm acreage for each county

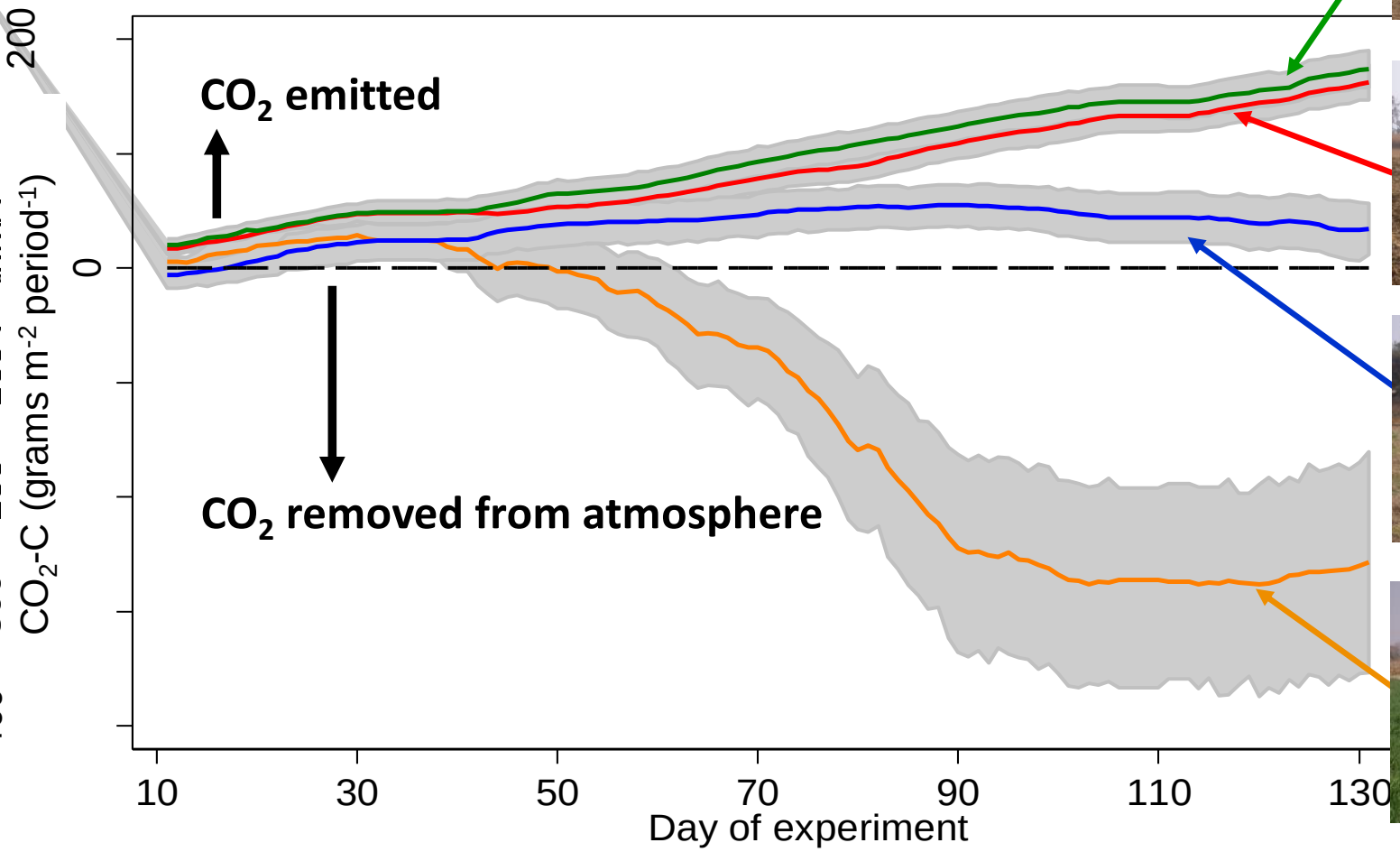
Current adoption of Cover Crops (~6%)

- **12% or less of surveyed fields used cover crops or double cropping (Claassen et al., 2018)**



Based on 2017 USDA census data of cover crop land use practice by farm acreage for each county

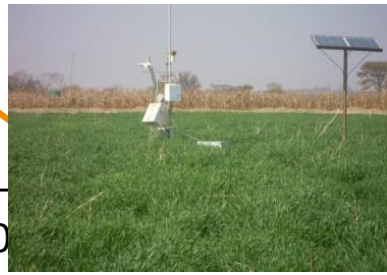
We need to keep soils productive and minimize soil carbon loss—any Cover Crop will reduce soil emissions




Untilled


Tilled


Blue Lupin Cover Crop


Wheat Cover Crop

1.1 US ton CO_2–C per acre per year

Source: O'Dell et al., 2015

Example in the news—the only two practices mentioned in this article were No-till and Cover Crops

The following is a quote from article by Georgina Gustin, Dec 26, 2019 at: https://insideclimatenews.org/news/26122019/agriculture-climate-change-flood-recovery-sustainable-farming-cover-crops-2019-year-review

" As millions of acres of American farmland sat under historic floodwaters last spring, a remarkable pattern began to emerge.

Even a**m**ong fields that sat side-by-side, with the same crops and the same soil type, researchers and farmers noticed that some bounced back faster than others.

What made the difference?

The fields that were slow to drain and remained waterlogged longer had been farmed conventionally — tilled, left bare and unplanted over the winter. **The fields that drained quickly and were ready for sowing hadn't been tilled in years and had been planted every winter with cover crops** such as rye and clover, which help control erosion, improve soil health and trap carbon in the soil. "

Side-by-side fields

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Two fields after the 2019 flooding: The field on the left had been farmed for several years using cover crops and no-till practices. The field on the right, with standing water, had been farmed with conventional tillage and no cover crops. Credit: Courtesy of Rob Myers/University of Missouri

Further, Secretary of Agriculture Sonny Perdue views expressed in the article …

More excerpts from article by Georgina Gustin, Dec 26, 2019 at:

https://insideclimatenews.org/news/26122019/agriculture-climate-change-flood-recovery-sustainable-farming-cover-crops-2019-year-review

" Even Sonny Perdue, the conservative Secretary of Agriculture who questions the link between human activity and climate change, has countenanced the idea of a cap-and-trade system.

"*Farmers and producers have been really intense victims of climate change*," Perdue said in a budget hearing in April.

"*We've been really guilty of not talking about how farmers can be part of the solution*," he said. "*It's amazing the tons of greenhouse gas and CO_2 emissions that we can capture in our soils if we have, I think, the incentivization of maybe a carbon market from agriculture do that*." "

Many government agencies, universities and organizations have contributed to our research

- **Our research has been supported by:**
  - USDA United States Department of Agriculture
  - USAID FROM THE AMERICAN PEOPLE
  - National Oceanographic and Atmospheric Administration (NOAA)
  - DuPont Tate & Lyle BioProducts™
  - UTIA INSTITUTE OF AGRICULTURE THE UNIVERSITY OF TENNESSEE
- **We want to move from Research to Application!**

How do we increase adoption?
Simply Pay Farmers

- **Incentives that work include USDA/NRCS programs:**
  - **Conservation Reserve Program (CRP)** pays farmers for not farming highly erodible land
  - **Conservation Stewardship Program (CSP)** pays farmers for adopting new conservation practices
  - **Environmental Quality Incentives Program (EQIP)** pays farmers up to 3 years to plant cover crops
  - **Plus NRCS provides the knowledge and support to farmers for implementation**
- **Maintaining robust support for CRP, CSP, EQIP, and NRCS is critical!**

EQIP and other NRCS programs provide support for EPA's Clean Air and Water Acts

- USDA NRCS U.S. Department of Agriculture Natural Resources Conservation Service **EQIP** provides financial and technical assistance to agricultural and forestry producers to address natural resource concerns and deliver environmental benefits such as **improved water and air quality, conserved ground and surface water, reduced soil erosion and sedimentation…**
- EPA United States Environmental Protection Agency **works to ensure that:**
  - **Americans have clean air, land and water**
    - EPA Clean Air and Water Acts (https://www.performance.gov/EPA/)
- **Agriculture contributes directly to sustainable stewardship of the land, air and water.**
- An ounce of prevention is worth a pound of cure
  - **Prevention is what NRCS does!**

For an Immediate First Step Forward: Pay Farmers for applying <u>Both</u> No-till and Cover Crops

- Many agencies and programs are working together to improve soils and lessen climate impacts, but we need to get started NOW
- **There needs to be a designated leader for this new, targeted program, to ensure implementation, oversight, management, and monitoring**

By simplifying the management practices we reward—No-till and Cover Crops—We can produce a substantial impact soon

- There is already an organization/program in place that can help administer a program to quantify results and establish a data and reporting system
- The Conservation Technology Information Center is promoting the Operational Tillage Information System (OpTIS) to advance the development of tools for verification and monitoring of cover crops, tillage, and soil health
  - CTIC is a membership-based non-profit that works to champion, promote, and provide information on economically and environmentally sustainable agricultural systems
  - Conservation adoption and impact data at: www.ctic.org

Next Steps

- There are a lot of USDA/NRCS programs rewarding farmers for over 150 practices
- We see a pressing need to have a big impact ASAP –
  - How can we sequester the most carbon?
- One simple/easy solution:
  - Increase adoption of No-till and Cover Crops by rewarding farmers
- What are your thoughts?
- **How can we assist?**
  - We are here to answer your questions on healthy soils and soil carbon sequestration
  - Contact us at: debodell3@gmail.com and eash@utk.edu

Appendix

- Summary
- Supporting data
- Highlights – history and results
- References

Summary

GOAL

Accelerate adaptation of agriculture to climate change while enhancing productivity and profit

STRATEGY

By increasing adoption of **no-till and cover crops** through incentives, we can jumpstart change and produce a substantial impact on food security and climate change resilience

We want to move forward immediately, so as to maintain U.S. leadership

BACKGROUND

- The necessary steps to improve agricultural sustainability and address climate change are well recognized — **no-till and cover crops**
- Federal programs (USDA-NRCS) already acknowledge this, but implementation does not target these practices

TACTICS

- Implement a program, **rewarding farmers for adopting no-till and cover crops**
- Construct/Install/Establish/Implement light weight administration and monitor cost of implementation
- Monitor, report and verify adoption
- Quantify carbon sequestration
- Quantify and report program benefits

United States Department of Agriculture Economic Research Service (ERS) Reports

- Evidence also suggests, however, that **long-term gains in soil health can be achieved only through consistent application of a suite of practices that includes minimal tillage and practices that increase (1) residue cover and (2) the portion of the year soil is covered by a growing crop (using cover crops, for example)** (USDA, NRCS, 2014).
  - ERS Report 2019: Agricultural Resources and Environmental Indicators
- None of the practices alone are capable of achieving the Gulf hypoxia goals of a 45-percent reduction in both N and P delivered. When applied individually, widespread adoption of (1) nutrient management in combination with erosion control or (2**) cover crops in combination with erosion control hold the greatest potential for reducing N (32-38 percent) and P (26-29 percent)**
  - ERS Report 2018: Reducing Nutrient Losses From Cropland in the Mississippi/Atchafalaya River Basin: Cost Efficiency and Regional Distribution

Our data from Lesotho, Zimbabwe, Ohio and Tennessee clearly shows that cover crops and no-till reduce CO_2 emissions

Paying Farmers has been shown to be the most effective means for turning Principles into Action!

Turning Principles into Action = Results!

Data Supporting Cover Crops and No-till C-Sequestration

Micrometeorological studies comparing the net ecosystem exchange (NEE) of CO_2 between reduced tillage/no-till practices as compared with conventional tillage.

The units are in metric tons of CO_2 per acre per year. Positive numbers indicate that the reduced/no-till emits less than conventional tillage. Negative numbers indicate that the reduced/no-till emits more than conventional tillage.

Positive numbers indicate that the cover crop is sequestering CO_2 and negative numbers indicate the cover crop is emitting CO_2.

Differences in CO_2 emissions between reduced/no-till and conventional tillage

Location	Crop	Year	t CO_2 ac^{-1} yr^{-1}	Data Source
N. central OH	Maize	2015	2.02	O'Dell et al., 2018
Harare, Zimbabwe	Maize	2013-2014	2.36	O'Dell et al., 2019, in review
Harare, Zimbabwe	Maize	2014-2015	6.24	O'Dell et al., 2019, in review
Pullman, WA	Garbanzo bean	2012-2013	2.47	Chi et al., 2016
El Reno, OK	Winter wheat	2016-2017	-0.97	Wagle et al., 2019
El Reno, OK	Canola	2016-2017	-2.90	Wagle et al., 2019
Central Iowa	Maize, soybean and cover crops	2016-2017	4.73	Dold et al., 2019
			1.99	

CO_2 Sequestration/emissions for various cover crops

Location	Crop	Tillage Practice	Year	t CO_2 ac^{-1} yr^{-1}	Data Source
Harare, Zimbabwe	Wheat	No-till	2013	4.63	O'Dell et al., 2015
Harare, Zimbabwe	Blue lupin	No-till	2013	-1.05	O'Dell et al., 2015
Lonzee, Belgium	Winter wheat	Reduced tillage	2004-2005	11.36	Moureaux et al., 2008
Hazel Green, AL	Winter wheat	No-till	2007	1.44	Gebremedhin et al., 2012
Hazel Green, AL	Winter wheat	No-till	2008	1.45	Gebremedhin et al., 2012
Hazel Green, AL	Winter wheat	No-till	2009	0.72	Gebremedhin et al., 2012
El Reno, OK	Winter wheat	No-till	2016-2017	9.25	Wagle et al., 2019
El Reno, OK	Winter wheat	Tilled	2016-2017	10.22	Wagle et al., 2019
El Reno, OK	Canola	No-till	2016-2017	3.26	Wagle et al., 2019
El Reno, OK	Canola	Tilled	2016-2017	6.17	Wagle et al., 2019
				4.75	

"Natural Climate Solutions" that mitigate climate change

- Both land and oceans sequester some of the excess fossil fuel CO_2 emissions in the atmosphere (The Carbon Cycle)
- Land types—forests, grasslands, wetlands and even agriculture—can absorb some of the excess emissions
  - These represent the "natural climate solutions"
- Forests are the largest land based carbon sinks (USGCRP, 2018)
- But Agriculture is also a land use and is intensively managed
- Agriculture grows plants so it can sequester carbon —but currently it sequesters very little
- **Therefore Agriculture has great potential to increase carbon sequestration**

Cover Crops and No-till mitigate and adapt to climate change and increase agricultural sustainability

- These practices mitigate climate change by
  - **Capturing more atmospheric CO_2**
- Increase Agriculture's ability to adapt to climate change by
  - **Enhancing drought and flood resilience**
- Cover crops and no-till increase soil and agricultural sustainability
- Maintain profitability by increasing soil carbon and improving soil health
- Reduce emissions from losses in the Conservation Reserve Program

Greater Soil carbon increases Soil quality and sustains yields

- Plants harvest sun energy and atmospheric CO_2, producing organic carbon building blocks (organic matter) for:
  - leaves, stems, and roots
- However, organic carbon can be decomposed and emitted as CO_2 back to the atmosphere
- To reduce decomposition rate, tillage must be minimized
- As organic matter builds on the soil surface and in plant roots, soil carbon increases, that also increases soil:
  - water infiltration (percolation and permeability)
  - resistance to erosion
  - resilience to erratic climate (floods and drought)

Supporting evidence for Cover Crops and No-till Soil carbon sequestration

- Some studies have found that no-till on its own does not sequester soil carbon—a meta-analysis (Luo et al., 2010) found no significant difference in soil carbon between no-till and conventional tillage
- But the same analysis showed that combined no-till and double cropping sequester carbon
  - NOTE: Double cropping is the practice of harvesting two crops in 1 year. Cover cropping often involves planting two crops in 1 year but harvesting only one crop, although cover crops may be grazed or harvested for silage but not grain or seed (Claassen et al., 2018, USDA-NRCS, 2014)

The science going back 35 years

- **Studies of long-term tillage and residue effects on soil quality have been going on since the 1980's**
  - Karlen, et al. (1994): **Long-term tillage effects on soil quality**
  - Karlen, et al. (1994): **Crop residue effects on soil quality following 10-years of no-till corn**
- **Recent research**
  - Abdalla et al., (2014) **Assessing the combined use of reduced tillage and cover crops for mitigating greenhouse gas emissions from arable ecosystem**
- **FAO adopted Conservation Agriculture in 2001**
  - Minimal soil disturbance
  - Maintain residue cover
  - Crop rotation

http://www.fao.org/conservation-agriculture/overview/principles-of-ca/en/

Science, USDA and Farmers support these results

- **Cover crops and no-till:**
  - Conserve resources including water, soil and soil organic matter
  - Reduce dependence on chemical inputs
  - Reduce use of fossil fuels required by the tillage process
  - Maintain and improve yields over time
  - Improve soil quality
- **The sustainability co-benefits of no-till and cover crops (while maintaining crop residue in the field) include:**
  - Reduced soil erosion and degradation
  - Reduced surface runoff, improving water quality and reducing loss of nutrients
  - Improved soil structure, increasing water infiltration (reducing flooding impacts) and enhancing resilience to drought
  - Increased soil organic matter which improves soil quality and crop yield, while reducing dependence on chemical fertilizer inputs

Ag & Grasslands greatest potential pathways in article: Natural Climate Solutions for the United States (Fargione et al., 2018)

- **Avoided Grassland Conversion**
  - "The emissions from grassland conversion exceed the emissions from forest conversion because both the rate of conversion and the per hectare emissions are higher. Cropland expansion is a major cause of conversion that affects grasslands much more than forests. The higher rate of emissions occurs because the **conversion of grasslands to croplands results in a 28% loss of soil carbon from the top meter of soil**. This generates 125 Mg CO_2e ha^{-1} in emissions, comprising 81% of the emissions from grassland conversion."
- **Cover Crops**
  - "Cover crops, grown when fields are normally bare, provide additional carbon inputs to soils. Growing cover crops on the 88 Mha of the five primary crops in United States not already using cover crops presents a substantial opportunity for mitigation (103 Tg CO_2e $year^{-1}$).
  - Cover crops are increasingly used by U.S. farmers to improve soil health, yields, and yield consistency."

Lessons from the Dust Bowl, Gove Hambidge, 1938 states:

"It will be evident from the discussion so far that in general nothing is more vital to good soil management than providing for the regular and systematic return of organic matter to the soil."

- Page 22 of Soils and Men, A Summary, by Gove Hambidge, in the USDA Yearbook of Agriculture, 1938
- A US Department of Agriculture government report following the Dust Bowl about soil maintenance and restoration in relation to farming. This includes information about laws and agricultural practices leading up to the dustbowl and reforms enacted to restore topsoil.

References in Front Matter

Claassen, R., Bowman, M., McFadden, J., Smith, D., Wallander, S. (2018). Tillage Intensity and Conservation Cropping in the United States, EIB-197, U.S. Department of Agriculture, Economic Research Service

Bot, A. and Benites, J. (2001). Conservation agriculture: case studies in Latin America and Africa (No. 78). U.N. Food and Agriculture Organization (FAO).

O'Dell, D., Sauer, T. J., Hicks, B. B., Thierfelder, C., Lambert, D. M., Logan, J., & Eash, N. S. (2015). A short-term assessment of carbon dioxide fluxes under contrasting agricultural and soil management practices in Zimbabwe. Journal of Agricultural Science, 7(3), 32-48.

Evans, J., Banda, A. and Seymour T. (1999). Opportunities for better soil management - Malawi.

Fargione, J. E., Bassett, S., Boucher, T., Bridgham, S. D., Conant, R. T., Cook-Patton, S. C., … Griscom, B. W. (2018). Natural climate solutions for the United States. Science Advances, 4(11), eaat1869.

USGCRP (2018). Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report [Cavallaro, N., Shrestha, G., Birdsey, R., Mayes, M. A., Najjar, R. G., Reed, S. C. , Romero-Lankao, P., and Zhu, Z. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 878 pp.

References for Data Supporting Cover Crops and No-till C-Sequestration

Anthoni, P. M., Freibauer, A., Kolle, O., & Schulze, E. D. (2004). Winter wheat carbon exchange in Thuringia, Germany. Agricultural and Forest Meteorology, 121(1-2), 55-67.

Bajgain, R., Xiao, X., Basara, J., Wagle, P., Zhou, Y., Mahan, H., Gowda, P., McCarthy, H.R., Northup, B., Neel, J. and Steiner, J. (2018). Carbon dioxide and water vapor fluxes in winter wheat and tallgrass prairie in central Oklahoma. Science of the Total Environment, 644, pp.1511-1524.

Dold, C., Hatfield, J. L., Prueger, J. H., Sauer, T. J., Moorman, T. B., & Wacha, K. M. (2019). Impact of Management Practices on Carbon and Water Fluxes in Corn–Soybean Rotations. Age, 2(1), 0.

Gebremedhin, M. T., Loescher, H. W., & Tsegaye, T. D. (2012). Carbon Balance of No-Till Soybean with Winter Wheat Cover Crop in the Southeastern United States. Agronomy Journal, 104(5), 1321.

Hernandez-Ramirez, G., Hatfield, J. L., Parkin, T. B., Sauer, T. J. and Prueger, J. H. (2011). 'Carbon dioxide fluxes in corn-soybean rotation in the midwestern U.S.: Inter- and intra-annual variations, and biophysical controls', Agricultural and Forest Meteorology, 151(12), pp. 1831–1842.

Hollinger, S., Bernacchi, C., and Meyers, T. (2005). 'Carbon budget of mature no-till ecosystem in North Central Region of the United States', Agricultural and Forest Meteorology, 130(1), 59-69.

Moureaux, C., Debacq, A., Hoyaux, J., Suleau, M., Tourneur, D., Vancutsem, F., Bodson, B. and Aubinet, M. (2008). Carbon balance assessment of a Belgian winter wheat crop (Triticum aestivum L.). Global Change Biology, 14(6), pp. 1353–1366.

O'Dell, D., N.S. Eash, B.B. Hicks, J.N. Oetting, T.J. Sauer, D.M. Lambert, J. Logan, W.C. Wright, and J.A. Zahn. (2018). Reducing CO 2 flux by decreasing tillage in Ohio: Overcoming conjecture with data. J. Agric. Sci. 10:1–15.

O'Dell, D., Sauer, T. J., Hicks, B. B., Thierfelder, C., Lambert, D. M., Logan, J., and Eash, N. S. (2015). A short-term assessment of carbon dioxide fluxes under contrasting agricultural and soil management practices in Zimbabwe. Journal of Agricultural Science, 7(3), 32-48.

O'Dell, D., N.S. Eash, B.B. Hicks, J.N. Oetting, T.J. Sauer, D.M. Lambert, C. Thierfelder, T. Muoni, J. Logan, J.A. Zahn, and J.J. Goddard. (2019). Conservation agriculture as a climate change mitigation strategy in Zimbabwe. International Journal of Agricultural Sustainability (in review).

Poeplau C., Don A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops - A meta-analysis. Agric Ecosyst Environ 200:33–41.

Chi, J., Waldo, S., Pressley, S., O'Keeffe, P., Huggins, D., Stöckle, C., Pan, W.L., Brooks, E. and Lamb, B. (2016). Assessing carbon and water dynamics of no-till and conventional tillage cropping systems in the inland Pacific Northwest US using the eddy covariance method. Agricultural and Forest Meteorology, 218-219, 37–49.

Ruan, L. and Philip Robertson, G. (2013). Initial nitrous oxide, carbon dioxide, and methane costs of converting conservation reserve program grassland to row crops under no-till vs. conventional tillage. Global Change Biology, 19(8), pp.2478-2489.

Suyker, A. E. and Verma, S. B. (2012). 'Gross primary production and ecosystem respiration of irrigated and rainfed maize-soybean cropping systems over 8 years', Agricultural and Forest Meteorology. Elsevier B.V., 165, pp. 12–24.

Verma, S. B., Dobermann, A., Cassman, K. G., Walters, D. T., Knops, J. M., Arkebauer, T. J., Suyker, A. E., Burba, G. G., Amos, B., Yang, H., Ginting, D., Hubbard, K. G., Gitelson, A. A. and Walter-Shea, E. A. (2005). 'Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems', Agricultural and Forest Meteorology, 131(1–2), pp. 77–96.

Wagle, P., Gowda, P. H., Manjunatha, P., Northup, B. K., Rocateli, A. C., & Taghvaeian, S. (2019). Carbon and water dynamics in co-located winter wheat and canola fields in the U.S. Southern Great Plains. Agricultural and Forest Meteorology, 279, 107714.

Zenone, T., Chen, J., Deal, M.W., Wilske, B., Jasrotia, P., Xu, J., Bhardwaj, A.K., Hamilton, S.K. and Philip Robertson, G. (2011). CO2 fluxes of transitional bioenergy crops: effect of land conversion during the first year of cultivation. Gcb Bioenergy, 3(5), pp.401-412.

References in the Appendix

Abdalla, M., Hastings, A., Helmy, M., Prescher, A., Osborne, B., Lanigan, G., Forristal, D., Killi, D., Maratha, P., Williams, M. and Rueangritsarakul, K. (2014). Assessing the combined use of reduced tillage and cover crops for mitigating greenhouse gas emissions from arable ecosystem. Geoderma, 223, pp.9-20.

FAO (2019). Conservation Agriculture principles. Available at: http://www.fao.org/conservation-agriculture/overview/principles-of-ca/en/ (Accessed: 29 January 2020).

Fargione, J. E., Bassett, S., Boucher, T., Bridgham, S. D., Conant, R. T., Cook-Patton, S. C., … Griscom, B. W. (2018). Natural climate solutions for the United States. Science Advances, 4(11), eaat1869.

Hambidge, G. (1938). Soils and Men-A Summary, In USDA Yearbook of Agriculture 1938. United States Department of Agriculture. p 22.

Karlen, D. L., Wollenhaupt, N. C., Erbach, D. C., Berry, E. C., Swan, J. B., Eash, N. S., & Jordahl, J. L. (1994). Long-term tillage effects on soil quality. Soil and Tillage Research, 32(4), 313–327.

Karlen, D. L., Wollenhaupt, N. C., Erbach, D. C., Berry, E. C., Swan, J. B., Eash, N. S., & Jordahl, J. L. (1994). Crop residue effects on soil quality following 10-years of no-till corn. Soil and Tillage Research, 31(2-3), 149–167.

Luo, Z., Wang, E., & Sun, O. J. (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agriculture, ecosystems & environment, 139(1-2), 224-231.

USDA-NRCS. (2014). NRCS Cover Crop Termination Guidelines.