Farm To Regional Scale Integration Network

agri benchmark

Carbon Farming with No-till and Straw Incorporation

A Reality Check

Webinar organized by *agri benchmark* Cash Crop and Farm to Regional Scale Integration Network

November 16th, 16:00 h (UTC +2)

Carbon Farming with No-tillage

Presentation outline

- Context
- Review: No-tillage and soil carbon stocks
- Additional considerations

Carbon Inputs > Carbon Outputs

Carbon Inputs	Carbon Outputs
• Roots/Rhizodeposits	• Grain
• Residue	• Residue
• Amendments	• Erosion
• Deposition	• Efflux/Emission (CO_2, CH_4)
	• Leaching

Haddaway *et al. Environ Evid* (2017) 6:30
DOI 10.1186/s13750-017-0108-9

Environmental Evidence

SYSTEMATIC REVIEW Open Access

How does tillage intensity affect soil organic carbon? A systematic review

Neal R. Haddaway[1*], Katarina Hedlund[2], Louise E. Jackson[3], Thomas Kätterer[4], Emanuele Luga
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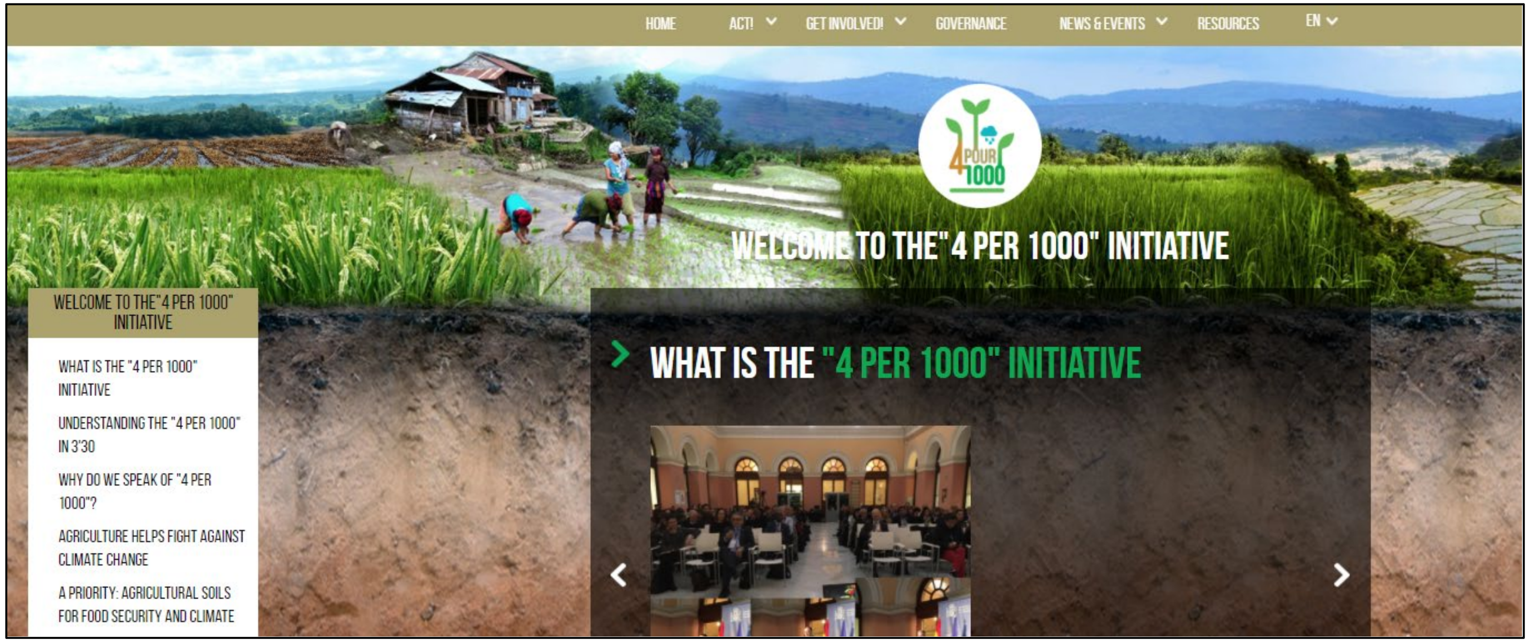


A Role for Agriculture?

Greenhouse gas mitigation initiatives

Agroecosystem Carbon Balance

Inputs & Outputs, Simplified

Carbon Inputs > Carbon Outputs

Carbon Inputs:

- Roots/Rhizodeposits
- Residue
- Amendments
- Deposition

Carbon Outputs:

- Grain
- Residue
- Erosion
- Efflux/Emission (CO_2, CH_4)
- Leaching

Soil Carbon Accrual for Cropland

Three general strategies

No-Tillage

Description and use

- *A system of planting crops into untilled soil by opening a narrow slot or trench only of sufficient width and depth to obtain proper seed coverage* (R. Derpsch)
- Also referred to as ‘zero tillage’, ‘direct seeding, or ‘slot planting’.
- Practiced on 42 million hectares in US
  (USDA-NASS, 2017)

No-Tillage and Soil Carbon Stocks

What does the literature say?

Individual Study Results

≈1970 to ≈1990

Blevins, R.L., G.W. Thomas, M.S. Smith, W.W. Frye, and P.L. Cornelius. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. Soil Tillage Res. 3:135-146.

- No-till (NT) > Conventional till (CT) at near-surface depths
- Assessments limited to surface 30 cm
- Soil bulk density not always reported

Depth (cm)	N rate (kg/ha)	Unlimed Organic C NT	Unlimed Organic C CT
0—5	0	2.15	1.25
	84	2.95	1.40
	168	2.80	1.39
	336	2.93	1.46
5—15	0	1.09	1.38
	84	1.28	1.34
	168	1.36	1.34
	336	1.15	1.49
15—30	0	0.57	0.78
	84	0.94	1.01
	168	0.66	0.70
	336	0.90	0.94

≈2x greater

Blevins et al. (1983)

Meta-Analysis

West and Post (2002)

West, T.O., & Post, W.M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal, 66*, 1930-1946.

Domain	Global
Data	67 long-term experiments; 276 paired treatments
Depth	0-30 cm

Key findings:

- SOC stocks: NT > CT
- 85% of sequestered C in NT occurred in the top 7 cm of soil
- NT sequestration rate = 48 g C/m^2/yr

Meta-Analysis

VandenBygaart et al. (2003)

VandenBygaart, A., Gregorich, E.G., & Angers, D.A. (2003). Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science, 83*, 363-380.

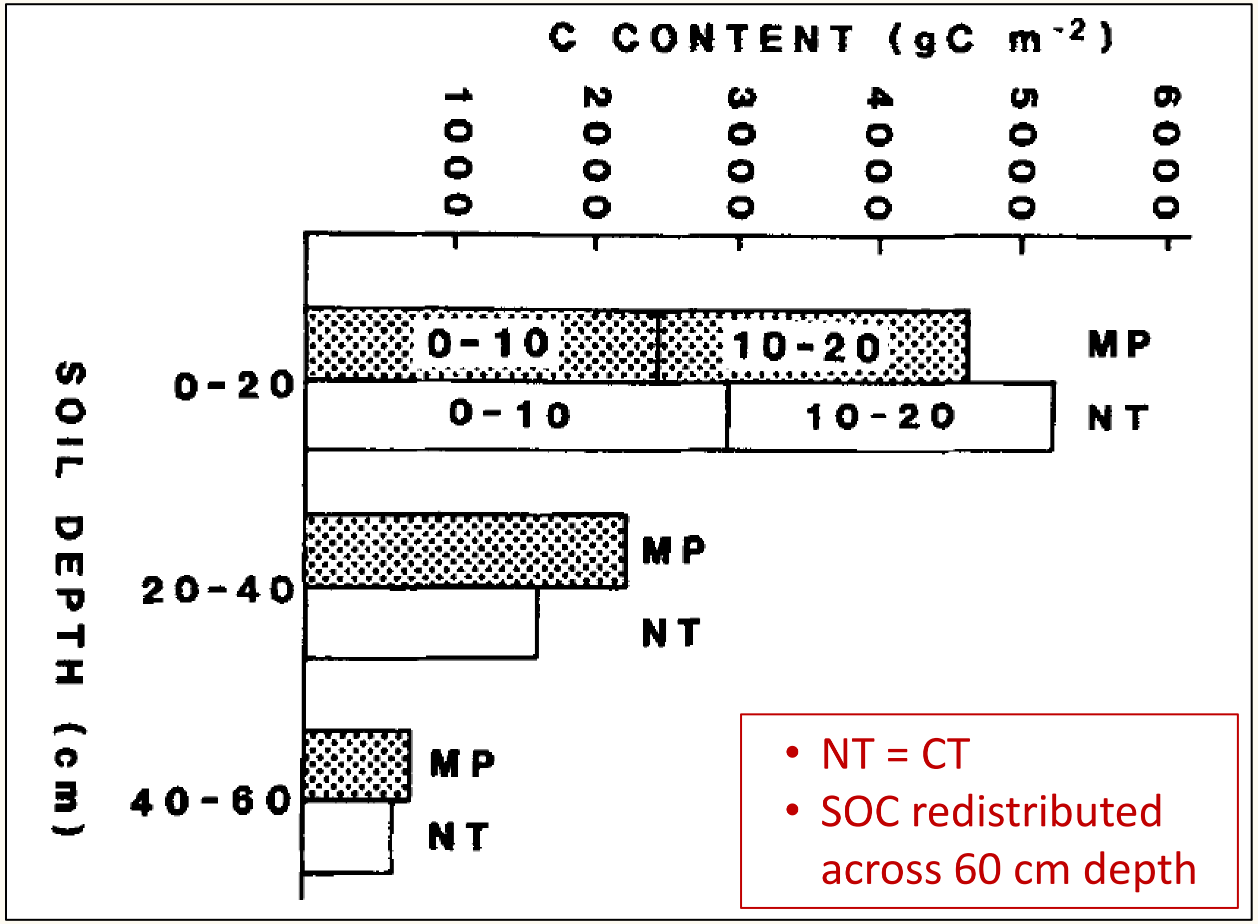
Domain	Canada
Data	62 studies; 291 paired treatments
Depth	To 37.5 cm in W. Canada; 70 cm in E. Canada

Key findings:

- SOC stocks: NT = CT
- Strong regional difference in NT and SOC stocks:
  - W. Canada: 32 g $C/m^2/yr$
  - E. Canada: -7 g $C/m^2/yr$

What was happening in eastern Canada?

Angers et al. (1997)



Angers et al. (1997)

- Inversion of residues in CT to depth with limited aeration
- NT may not confer a yield benefit relative to CT in eastern Canada
- Earthworm activity in eastern Canada NT fields may facilitate greater residue assimilation and decomposition

VandenBygaart et al. (2003)

Documenting Meta-Analysis Caveats

Baker et al. (2007)

Baker, J.M., Ochsner, T.E., Venterea, R.T., & Griffis, T.J. (2007). Tillage and soil carbon sequestration—What do we really know? *Agriculture, Ecosystems & Environment, 118*, 1-5.

- Tillage differences in root length density (RLD) between NT and CT:
  - >RLD in **NT** at surface depths
  - >RLD in **CT** at lower depths
- Shallow sampling of tillage treatments favors >SOC in NT than CT
- Need deeper soil depth sampling for SOC, along with gas exchange measurements

"The widespread belief that conservation tillage favors carbon sequestration may simply be an artifact of sampling methodology."

Baker et al. (2007)

Reviews and Meta-Analyses

2008-2015

Citation	*Govaerts et al. (2009)*	*Luo et al. (2010a)*	*Luo et al. (2010b)*	*Aguilera et al. (2013)*
Domain	Global	Australia	Global	Mediterranean
Data	78 studies	39 publications	69 studies	21 publications
Depth	0-108 cm	0-30 cm	0->40 cm	34 cm (mean)
Key Findings	NT>CT in 40 studies NT<CT in 7 studies NT=CT in 31 studies	NT>CT	NT=CT	NT increased SOC by 44 g C/m^2/yr

Reviews and Meta-Analyses

2016-present

Citation	*Haddaway et al. (2017)*	*Ogle et al. (2019)*	*Bai et al. (2019)*	*Das et al. (2022)*
Domain	Warm temperate and boreal regions	Global	Global	Tropical and subtropical regions
Data	351 studies	178 sites	417 publications	84 publications
Depth	0-15, 15-30, >30 cm	0->30 cm	0-10, 10-20, 20-50, and 50-100 cm	0–10, 10–20, 20–30, 30–40 and >40 cm
Key Findings	NT>CT, 0-15 cm NT=CT for soil profile	NT>CT, <20 cm NT<CT, >20 cm Greater uncertainty in SOC with depth	NT>CT, 0-10 cm NT<CT, 10-50 cm NT=CT, 50-100 cm	NT=CT, all depths

Take home message from meta-analyses…

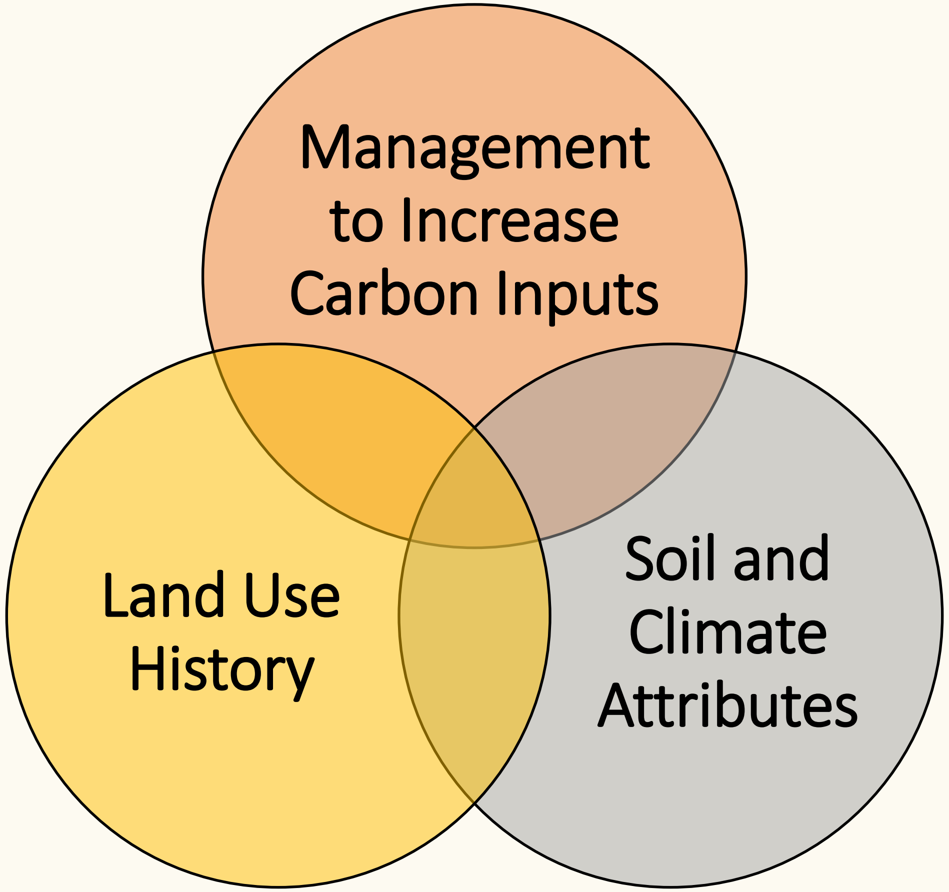
- No-tillage is not a universal strategy to increase soil carbon
  - NT>CT at surface depths
  - NT<CT at lower depths
  - NT=CT across profile

- But there's more to the story…

No-tillage and Soil Carbon

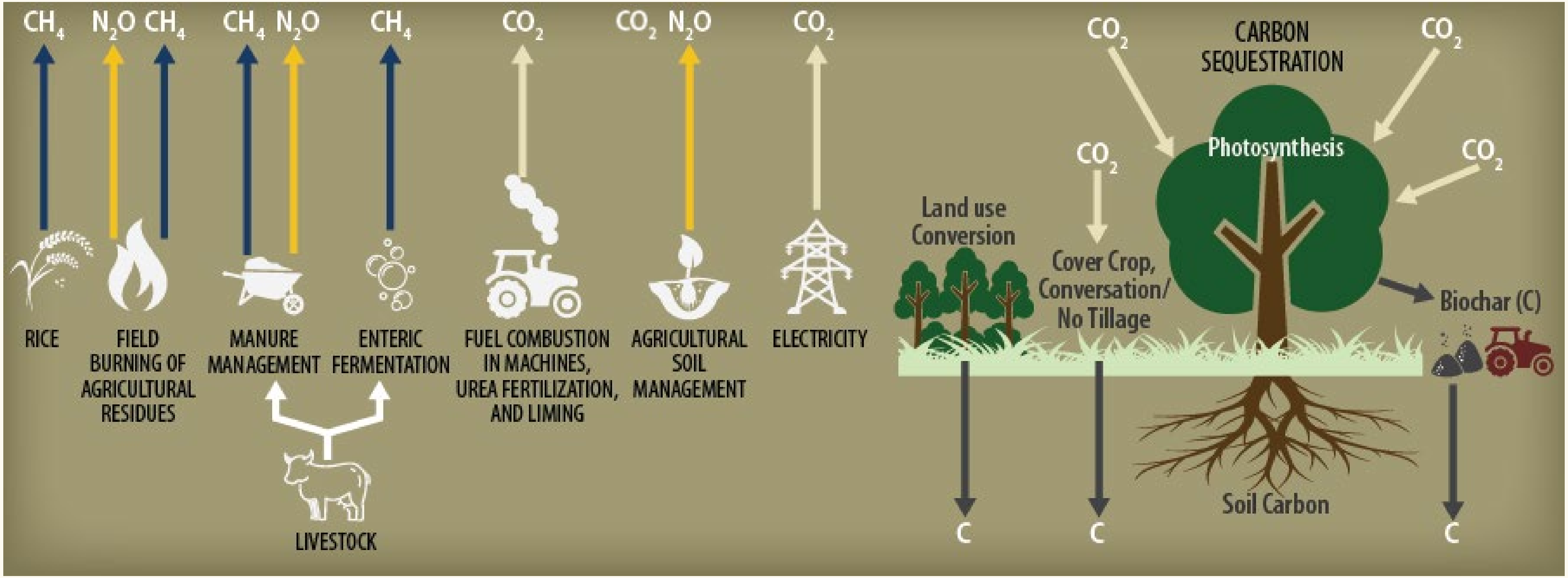
Are there ideal conditions for an SOC accrual?

- *Land use history* Croplands far from carbon saturation (Amelung et al., 2020)
- *Management* Intensified systems with high C inputs (Aguilera et al., 2013)
- *Climate* Tropical (dry/moist/wet) and Warm & Cool (moist) found to favor SOC accrual under NT (Ogle et al., 2019)
- *Soil type* Loamy, silty, clayey, sandy, depending on climate (Bai et al., 2019; Ogle et al., 2019)
- *Time* Greatest SOC increases observed after 20 yr (Bai et al, 2019)



Agroecosystem Greenhouse Gas Balance

Many sources, a few sinks



CRS (2018)

Global Warming Potential (GWP)

Putting GHG mitigation in a climate context

Global warming potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide.

For example…

- 1 CO_2 = 1 $CO_{2\ equiv.}$
- 1 CH_4 = 28 $CO_{2\ equiv.}$
- 1 N_2O = 265 $CO_{2\ equiv.}$

* 100-yr time horizon

Placing emission sources/sinks on a level playing field when considering GHG mitigation potential

Myhre et al. (2013)

Cropping Systems Evaluation - Mandan, ND USA

GWP & No-Tillage Example

Factor	- - - - - - - - - No-Tillage Management - - - - - - - - -		
	Spring wheat - Fallow	Continuous spring wheat	Spring wheat - Safflower - Rye
	- - - - - - - - - - kg $CO_{2equiv.}$ ha^{-1} yr^{-1} - - - - - - - - - -		
Seed production	21 b[†]	42 a	47 a
Fertilizer production	66 c	238 a	171 b
Pesticide production	112	82	99
Field operations	93 c	143 a	128 b
SOC change	69	-205	-1244
CH_4 flux	-19	-11	-14
N_2O flux	479	1658	799
Net GWP	**822**	**1948**	**-14**

[†] Negative numbers imply $CO_{2equiv.}$ gain (black) Positive number imply $CO_{2equiv.}$ loss (red). Means in a row with unlike letters differ ($P \leq 0.05$).

Liebig et al. (2019)

No-Tillage Management

Other Considerations

- ***Tail-pipe emissions*** Relative to CT, fewer field implement passes with NT
  - Lower CO_2 emissions from operations (West and Post, 2002)
- ***Improved fertility*** Soil fertility often improves under NT, reducing fertilizer N inputs
  - Lower CO_2 emissions from inputs (West and Post, 2002)
  - Lower N_2O emission from soil in humid climates (Six et al., 2004)
- ***Improved soil structure*** NT frequently improves aeration and water regulation
  - Greater CH_4 uptake and lower N_2O emission (Plaza-Bonilla et al., 2020; van Kessel et al., 2013)

Conclusions

Carbon Farming with No-tillage

- Increased soil carbon with no-tillage is not systemic
- There are conditions that appear to favor carbon accrual under no-tillage (e.g., history, climate, soil type, management)
- Many other factors in addition to soil carbon need to be considered to assess mitigation potential

References

Carbon Farming with No-Tillage

- Aguilera, E., Lassaletta, L., Gattinger, A., & Gimeno, B.S. (2013). Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agriculture, Ecosystems & Environment, 168*, 25-36.
- Amelung, W., Bossio, D.A., de Vries, W., Kögel-Knabner, I., Lehmann, J., Amundson, R., Bol, R., Collins, C., Lal, R., Leifeld, J., Minasny, B., Pan, G., Paustian, K., Rumpel, C., Sanderman, J., van Groenigen, J.W., Mooney, S., van Wesemael, B., Wander, M., & Chabbi, A. (2020). Towards a global-scale soil climate mitigation strategy. *Nature Communications, 11*.
- Amundson, R., & Biardeau, L. (2018). Opinion: Soil carbon sequestration is an elusive climate mitigation tool. *Proceedings of the National Academy of Sciences, 115*, 11652 - 11656.
- Angers, D.A., Bolinder, M.A., Carter, M.R., Gregorich, E.G., Drury, C.F., Liang, B.C., Voroney, R.P., Simard, R.R., Donald, R.G., Beyaert, R.P., & Martel, J. (1997). Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. *Soil & Tillage Research, 41*, 191-201.
- Bai, X, Huang, Y, Ren, W, et al. (2019). Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis. *Global Change Biology 25*, 2591– 2606. https://doi.org/10.1111/gcb.14658
- Baker, J.M., Ochsner, T.E., Venterea, R.T., & Griffis, T.J. (2007). Tillage and soil carbon sequestration—What do we really know? *Agriculture, Ecosystems & Environment, 118*, 1-5.
- Blevins, R.L., G.W. Thomas, M.S. Smith, W.W. Frye, and P.L. Cornelius. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. *Soil Tillage Res. 3,* 135-146.
- Das, S., Chatterjee, S., & Rajbanshi, J. 2022. Responses of soil organic carbon to conservation practices including climate-smart agriculture in tropical and subtropical regions: A meta-analysis. *Science of The Total Environment, 805*, 150428.
- Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J.A., & Dendooven, L. (2009). Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality. *Critical Reviews in Plant Sciences, 28*, 122 - 97.
- Haddaway, N.R., Hedlund, K., Jackson, L.E., Kätterer, T., Lugato, E., Thomsen, I.K., Jørgensen, H.B., & Isberg, P.E. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environmental Evidence, 6*, 1-48.
- Kravchenko, A., & Robertson, G.P. (2011). Whole-Profile Soil Carbon Stocks: The Danger of Assuming Too Much from Analyses of Too Little. *Soil Science Society of America Journal, 75*, 235-240.
- Luo, Z., Wang, E., & Sun, O.J. (2010a). Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: A review and synthesis. *Geoderma, 155*, 211-223.
- Luo, Z., Wang, E., & Sun, O.J. (2010b). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agriculture, Ecosystems & Environment, 139*, 224-231.
- Ogle, S.M., Alsaker, C., Baldock, J.A., Bernoux, M., Breidt, F.J., McConkey, B., Regina, K., & Vazquez-Amabile, G.G. (2019). Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. *Scientific Reports, 9*.
- Ogle, S.M., Breidt, F.J., & Paustian, K. (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry, 72*, 87-121.
- Pittelkow, C.M., Linquist, B.A., Lundy, M.E., Liang, X., Groenigen, K.J., Lee, J., Gestel, N.V., Six, J., Venterea, R.T., & Kessel, C.V. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research, 183*, 156-168.
- Plaza-Bonilla, D., et al. (2020) No-Till Farming Systems to Reduce Nitrous Oxide Emissions and Increase Methane Uptake. Chapter 19. In: Y. P. Dang et al. (eds.), *No-till Farming Systems for Sustainable Agriculture*. https://doi.org/10.1007/978-3-030-46409-7_19
- Powlson, D.S., Stirling, C.M., Jat, M.L., Gérard, B., Palm, C.A., Sánchez, P.A., & Cassman, K.G. (2014). Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change, 4*, 678-683.
- Six, J., Ogle, S.M., Breidt, F.J., Conant, R.T., Mosier, A.R., & Paustian, K. (2004). The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. *Global Change Biology, 10*, 155-160.
- van Kessel, C., Venterea, R.T., Six, J., Adviento-Borbe, M.A., Linquist, B.A., & van Groenigen, K.J. (2013). Climate, duration, and N placement determine N2 O emissions in reduced tillage systems: a meta-analysis. *Global change biology, 19 1*, 33-44.
- VandenBygaart, A. (2016). The myth that no-till can mitigate global climate change. *Agriculture, Ecosystems & Environment, 216*, 98-99
- VandenBygaart, A., Bremer, E., McConkey, B., Ellert, B.H., Janzen, H.H., Angers, D.A., Carter, M.R., Drury, C.F., Lafond, G.P., & Mckenzie, R.H. (2011). Impact of Sampling Depth on Differences in Soil Carbon Stocks in Long-Term Agroecosystem Experiments. *Soil Science Society of America Journal, 75*, 226-234.
- VandenBygaart, A., Gregorich, E.G., & Angers, D.A. (2003). Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science, 83*, 363-380.
- West, T.O., & Post, W.M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal, 66*, 1930-1946.
- Zhao, X., Liu, S., Pu, C., Zhang, X., Xue, J., Zhang, R., Wang, Y., Lal, R., Zhang, H., & Chen, F. (2016). Methane and nitrous oxide emissions under no-till farming in China: a meta-analysis. *Global change biology, 22 4*, 1372-84.

Carbon Farming with No-till and Straw Incorporation

A Reality Check

Thank you for your attention

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