Healthy Soils that Sequester Carbon: Representative Studies

- **General**

Lydia Olander et al, "Assessing Greenhouse Gas Mitigation Opportunities and Implementation Strategies for Agricultural Land Management in the United States", Technical Working Group on Agricultural Greenhouse Gases of Duke University's Nicholas Institute for Environmental Policy Solutions (T-AGG), Report NI R 11-09, November 2011

Zomer, R. J. et al (2017), "Global Sequestration Potential of Increased Organic Carbon in Cropland Soils," Scientific Reports 7(1), concluding that because almost all cropped soils have lost a large percentage of their pre-cultivation SOC, they have the potential to re-absorb carbon through the "adoption of improved or proper management".

- **Carbon Sequestration and Organic Matter in Organic Agriculture Generally**

Rodale Institute 2014, "Regenerative Organic Agriculture and Climate Change: A Down to Earth Solution to Global Warming" (30-year comparative farm systems trial concludes that we can sequester our current carbon emissions by transitioning to organic agriculture.

Food and Agriculture Organization of the United Nations, "Organic Agriculture and Carbon Sequestration: Possibilities and Constraints for the Consideration of Organic Agriculture Within Carbon Accounting Systems", Maria Muller-Lindenhauf, December 2009 (See studies referenced that support conclusion: "There is scientific evidence that organic agriculture can sequester more carbon than conventional agricultural practices or inhibit the carbon release. All available studies showed higher carbon stocks in organic systems.")

E. Ghabbour and G. Davies, "National Comparison of the Total and Sequestered Organic Matter Contents of Conventional and Organic Farm Soils", Northeast University and The Organic Center, 2017 Advances in Agronomy (study showed 26% more carbon in organic samples from 659 organic farms in 39 states compared to samples from 700 conventional farms in 48 states), Sept. 11, 201

- **Refraining from or reducing the application of synthetic fertilizers**

Yayeh Bitew and Melkamu Alemayehu, (2017 Review of 154 studies from 1998-2013) "Impact of Crop Production Inputs on Soil Health: A Review" Asian Journal of Plant Sciences 16: 109-131) (2017) (see text and Table 7 list of the impact of 13 insecticides and nematicides and 10 fungicides on soil health)

E.K. Bunemann, G.D. Schwenke and L. Van Zwieten (2006 Review of studies) "Impact of Agricultural Inputs on Soil Organisms- A Review", Australian Journal of Soil Research 44: 379) (2006) (See Table 4 Effects of Inorganic Fertilizers on Soil Organisms and Table 5 Comparative Effects of Inorganic and Organic Fertilizers on Soil Organisms

Heide Hermary, 2007 "Effects of Some Synthetic Fertilizers on the Soil Ecosystem" (synthetic nitrogen)

"Regenerative Organic Agriculture and Climate Change: A Down to Earth Solution to Global Warming "Rodale Institute 2014

Reducing 15% of synthetic nitrogen can sequester 68 metric tons of carbon. T-Agg.

Khan, Mulvaney and Ellsworth "Synthetic Nitrogen in Fertilizers Deplete Soil Nitrogen" Journal of Environmental Quality 2009 "Synthetic nitrogen fertilizers [are] promoting the loss of soil carbon and organic nitrogen".

- **Refraining from the application of certain synthetic pesticides, herbicides, and fungicides^**

Indigo Carbon and others in the carbon trading marketplace are providing carbon sequestration payments to farmers who are "reducing reliance on chemical and synthetic fertilizers and pesticides" as well as converting to rotational grazing. "Montana ranchers can now get paid to sequester carbon using rotational grazing practices," AgFunder, July 18, 2019.

E.K. Bunemann, G.D. Schwenke and L. Van Zwieten (2006 Review of studies) "Impact of Agricultural Inputs on Soil Organisms- A Review", Australian Journal of Soil Research 44: 379) (2006) (See Table 7 Effect of Animal Manures, Biosolids, and Composts on Soil Organisms, Table 8 Impact of Herbicides on Non-Target Soil Organisms, Table 9 Impact of Insecticides and Nematicides on Non-Target Soil Organisms, Table 10 Impact of Fungicides on Non-Target Soil Organisms, Table 11 Impact of Veterinary Health Products , Fumigants, and other Biological and Non-Chemical Plant Protection Measures on Non-Target Soil Organisms)

S. Hussain et al "Impact of Pesticides on Soil Microbial Diversity, Enzymes, and Biochemical Reactions" Ch 5 Advances in Agronomy Vol 102 (2009) (pesticides impact e.g., micro-organism proliferation, molecular interactions, enzyme activity, nitrogen-fixing, phosphorus-solubilizing, organic matter mineralization, nitrification and de-nitrification, ammonification, redox reactions, and methanogenesis)

D. Pimentel "Environmental and Economic Costs of the Application of Pesticides Primarily in the United States", Economic Development and Sustainability 229-252 (2005)

Yayeh Bitew and Melkamu Alemayehu, 2017 Review of 154 studies from 1998-2013) "Impact of Crop Production Inputs on Soil Health: A Review" Asian Journal of Plant Sciences 16: 109-131, 2017

E.K. Bunemann, G.D. Schwenke and L. Van Zwieten 2006 Review of studies "Impact of Agricultural Inputs on Soil Organisms- A Review", Australian Journal of Soil Research 44: 379) (2006)

M.A. Locke and R.M. Zablotowicz "Pesticides in Soil-Benefits and Limitations to Soil Health" USDA-ARS Southern Weed Science Research Unit ars.usda.gov

"Regenerative Organic Agriculture and Climate Change: A Down to Earth Solution to Global Warming" Rodale Institute 2014

"The Impact of Glyphosate on Soil Health: The Evidence to Date" Soil Association (reviewing studies showing impact on earthworms, mycorrhizal fungi spore viability and root colonization), 2016 or later

Druille, M. et al "Glyphosate Reduces Spore Viability and Root Colonization of Arbuscular Mycorrhizal Fungi" (2013), Applied Soil Ecology, 64, pp 99-103.

Zaller, J. G. et al "Glyphosate Herbicide Affects Belowground Interactions Between Earthworms and Symbiotic Mycorrhizal Fungi in a Model Ecosystem" (2014), Scientific Reports, 4, 5634.

Yamada, T., "Glyphosate Interactions with Physiology, Nutrition, and Diseases of Plants: Threat to Sustainability", European Journal of Agronomy, 31(3), pp. 111-113.

Gaupp-Berghausen, M. et al, "Glyphosate-based herbicides reduce the Activity and Reproduction of Earthworms and lead to Increased Soil Nutrient Concentrations" (2015), Scientific Reports, 5, p. 12886.

Dobberstein, John "Is Glyphosate Harming Your No-Tilled Soils?" (2017), No-Till Farmer, October 28, 2017, no-tillfarmer.com/articles

- **Establishment of perennial plantings, including federally funded buffer and filter strips surrounding agricultural fields as well as entire grassland fields and wetlands**

Ed Barbier "The Economic Value of Grassland Species for Carbon Storage", ScienceDaily, April 19, 2017 University of Wyoming, Northern Ariz Univ., Univ. of Illinois, Univ of Minn., Univ of Nebraska, W. Wash Univ., Univ of Michigan, Australis's Western Sydney Univ. (grasslands with diverse plant species have more carbon storage capacity)

John Marton et al "USDA Conservation Practices Increase Carbon Storage and Water Quality Improvement Functions: An Example from Ohio", Jan 2014 Restoration Ecology VOl. 22, No. 1, pp 117-124

"Rationally Managed Pastures Stock More Carbon Than No-Tilled Fields" Hizumi . S, de Filho and Brugnara, Frontiers Environ. Sci. Dec. 21, 2017

Silva et al "Review of the number of pasture studies on carbon sequestration (42 studies of carbon change by converting cropland to pasture and 50 studies of carbon sequestration in grasslands", 2016

Richard T. Conant, "Challenges and Opportunities for Carbon Sequestration in Grassland Systems", Vol. 9-2010, Food and Agriculture Organization

Mitsch et al "Conversion of cropland to carbon-rich wetlands increases soil organic carbon", 2012

Albrecht and Kandji "Carbon Sequestration in Tropical Agroforestry Systems" Agriculture Ecosystems & Environment 99 (1-1): 15-27, October 2003 [Agroforestry is the intercropping of trees with crops and/or animals.]

Grass or tree and shrub buffer strips of 35'width around production fields (minimum for reimbursement) to 65' (optimal width) provide important ecosystem services of absorbing nutrients and pesticides (up to 50%), sediment (75%), pathogens (60%) and water in addition to sequestering carbon. NRCS.usda.gov

- **Establishment or application of beneficial micro-organisms such as mycorrhizal fungi and otherwise restoring the fungal bacterial balance**

Dr. David C. Johnson, Institute for Sustainable Agricultural Research demonstrating that with the application of fungal-dominated compost, there was a 25-times increase in active soil fungal biomass and an annual average carbon capture of 10.27 metric tons of C per hectare per year, or 20-50 times the observed carbon increase in no-till soils tested (with the capacity for far more).

Dr. Christine Jones , Green Agriculture Stewardship Scheme Submission Inquiry into the role of (Australian) government in assisting farmers to adapt to the impacts of climate change

Peter Jeffries, Silvio Gianinazzi et al 2003 "The Contribution of Arbuscular Mycorrhizal Fungi in Sustainable Maintenance of Plant Health and Soil Fertility" Biology and Fertility of Soils Volume 37, Issue 1, page 1

Erik Verbruggen et al 2010 "Positive Effects of Organic Farming on Below-Ground Mutualists: Large-Scale Comparison of Mycorrhizal Fungal Communities in Agricultural Soils" New Phytologist Vol 186 Issue 4 pages 968 (comparing conventional, organic and pasture lands)

- **Pastured Animal Production**

"Negative Emissions Technologies and Reliable Sequestration: A Research Agenda 2019", National Academies of Sciences, Engineering and Medicine 2019 https://doi.org/10.17226/25259 "probably the most effective means of increasing soil carbon stocks on annual crop land is to convert to perennial vegetation, either for grazing and forage production, afforestation… or as conservation set aside. Perennial grasses, in particular, allocate a large fraction of their carbon assimilates to below-ground production…"

"Rationally Managed Pastures Stock More Carbon Than No-Tilled Fields" Hizumi . S, de Filho and Brugnara, Frontiers Environ. Sci. Dec. 21, 2017

Pawlok Dass and Benjamin Houlton, UC Davis John Muir Institute (2018), Environmental Research Letters, concluding that in 3 of 4 model California simulations (the 4th being that carbon emissions largely stop), grasslands and rangelands were more reliable carbon sinks than trees. (Grasslands sequester most of their carbon in soil while forests store it mostly in woody biomass and leaves. In unstable climate with warming, drought and fires, forest carbon sinks become carbon sources.)

D. Johnson, R. Weil et al "Sustainability of Management-Intensive Grazing Dairy Farms versus Conventional Confinement Dairy Farms" post-2013

Paige L. Stanley "Impacts of Soil Carbon Sequestration on Life Cycle Greenhouse Gas Emissions in Mid-Western USA Beef", Vol 162 May 2018 (noting the need for additional data including the impact of soil erosion on land used to produce confinement feed crops)

M. Silveira et al (2012) "Carbon Sequestration in Grazing Land Ecosystems", Doc SL373 U of Fla IFAS Extension (because 90% of carbon in pasture is stored in the ground and "because carbon stored below ground is more permanent than plant biomass, soil carbon sequestration in grazing lands provides a long-term alternative" to forests)

Ryals and Silver 2012, Ryals et al 2014 (rapidly increases soil organic carbon particularly when coupled with thin compost application

Conant, R. T et al (2017) "Grassland Management Impacts on Soil Carbon Stocks: A New Synthesis", Ecological Applications Vol 27 Issue 2 (confirming earlier conclusions that improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation all tend to lead to increased soil C, at rates ranging from .105 to more than 1Mg C/ha/yr. and additionally reviewing fire, silvopastoralism and reclamation)

Conant R. T. et al 2001 "Grassland Management and Conversion into Grasslands: Effects on Soil Carbon", Ecological Applications 11(2): 343-355 (Conversion of cropland to grassland sequesters more carbon)

Machmulller, Megan B. et al 2015 "Emerging Land Use Practices Rapidly Increase Soil Organic Matter", Nature Communications (three SE US farms studied for seven years accumulated carbon at 8 Mg/ha/yr. after conversion of cropland to managed intensive grazing)

A Greener World "A Breath of Fresh Air: The Truth about Pasture-Raised Livestock Production and Environmental Sustainability" 2015 (see studies cited therein) (Although cattle grazed on pasture may have a slower growth rate and thus produce more methane, it is significantly offset by the overall greenhouse gas benefits of pasture-based production systems, from carbon sequestration in the soil to lower methane production in their manure)

Griscom et al (2017), "Natural Climate Solutions" Proc. National Acad. Sci. 114 (44) 2 pp. 11645 (recognizing the contributions that grazing management can make to net global climate mitigation)

McSherry and Ritchie (2013) "Effects of Grazing on Grassland Soil Carbon: A Global Review" Glob. Chang. Biol. 19, pp 1347

Liebig, M. A. et al (2010), "Grazing Management Contributions to Net Global Warming Potential: A Long-Term Evaluation in the Northern Great Plains", J. Environ. Qual. 39, pp 799-809 (concluding that all three pasture types studied… both moderately and heavily grazed native pastures and a heavily grazed wheatgrass pasture… were significant sinks for SOC

Wang, T., Teague W, and Bevers S. (2015) "GHG Mitigation Potential of Different Grazing Strategies in the US Southern Great Plains", Economics (concluding that farms converting from continuous to managed paddock grazing in the region are likely net carbon sinks for decades)

Byrnes, R. et al (2018) "A Global Meta-Analysis of Grazing Impacts on Soil Health Indicators". Journal of Envir. Quality

Wenquin Chen et al "Improved Grazing Management May Increase Soil Carbon Sequestration in Temperate Steppes", Scientific Reports (2015) 5:10892

Union of Concerned Scientists "Greener Eggs and Ham: The Benefits of Pasture-Raised Swine, Poultry, and Egg Production" Kate Clancy Dec. 2016

- **No-Till and Conservation Tillage**

Conventional tillage systems, all other things being equal, can sequester 2/3 of the carbon as a no-till system. In a Beltsville (Md.) Farming System Project, soil organic carbon is expected to increase .014Mg ha/yr. in conventional tillage versus .021 in no-till.

Understanding the Importance of Soil, Climate and Farming Procedures on Soil Organic Carbon Sequestration; A Simulation Study in Australia, Godde CM et al, Front. Plant Sci. 2016

Kenneth R. Olson "Soil Organic Carbon Sequestration, Storage, Retention and loss in US Croplands" Geoderma Vol. 195-196 pp 201-206 (March 2013) [Prior studies erred in concluding there were gains in soil organic carbon with no-till, and there were likely losses but at a slower rate.]

Increased diversity and winter cover crops significantly increase soil organic carbon despite intensive tillage for weed control. Syswerda et al 2011

Zhongkui Luo et al, "Can No-Tillage Stimulate Carbon Sequestration in Agricultural Soils? A Meta-Analysis of Paired Experiments, Agriculture Ecosystems & Environment 139 (102) 224-231 October 2010 (finding that no-till increased soil carbon in the top 10cm of soil but reduced it at 20-40cm, and concluding that in most cases non-tillage does not increase total carbon in soil.)

D.S. Powlson et al "Limited Potential of No-Till Agriculture for Climate Change" Nature Climate Change 4, 678-683 (2014) [No-till is beneficial for soil quality and adaptation to climate change, but its role in mitigation is widely overstated.]

Humberto Blanco-Canqui , Rattan Lal, "No Tillage and Soil-Profile Carbon Sequestration: An On-Farm Assessment," Soil Science Society of America Journal 72 (3), 693-701 (2008) (no-till farming increases SOC in the upper layers of some soils but it does not store more carbon than plow till soils for the whole soil profile.)

Syswerda et al 2011 Increased diversity and use of winter cover crops significantly increases soil organic carbon despite intensive tillage for weed control

- **Use of More Diverse Crop Rotations**

McDaniel et al 2014 More diverse crop rotations produce higher SOC and microbial biomass

Tiemann et al 2015 More diverse crop rotations produce higher soil organic carbon and soil microbial biomass

Wickings 2012 (Use of several crops within a single rotation increase SOC because of the diversity of carbon compounds)

Davis et al 2012 (Use of several crops within a single rotation increase soil organic carbon and are as productive as monoculture while reducing need for inputs and providing additional ecosystem services

Syswerda et al 2011 Increased diversity and use of winter cover crops significantly increases soil organic carbon despite intensive tillage for weed control

- **Use of Cover Crops**

Use of winter cover crops leads to increased soil organic carbon in Texas, Kansas, and Nebraska Genhart et al 1994.

Syswerda et al 2011 Increased diversity and use of winter cover crops significantly increases soil organic carbon despite intensive tillage for weed control

The magnitude of the potential of cover crops to sequester carbon is debated. Zomer et al

The amount of carbon sequestered by cover crops can vary with soil type, management, elevation, and climate. Poeplau and Don, 2014, with colder climates more suited to long-term carbon storage.

The rate of sequestration was 0.22 tons/acre/year in one study. Ruis and Blanco-Canqui, 2017.

In one study, soil type rather than crop type and date of planting influenced the rate of sequestration. McDowell, Ruis and Blanco-Canqui, "Cover Crops ands Carbon Sequestration: Benefits to the Producer and the Planet", March 11, 2019.