Soil Carbon in Practice

Methods of Monitoring, Testing, and Improving Soil Carbon

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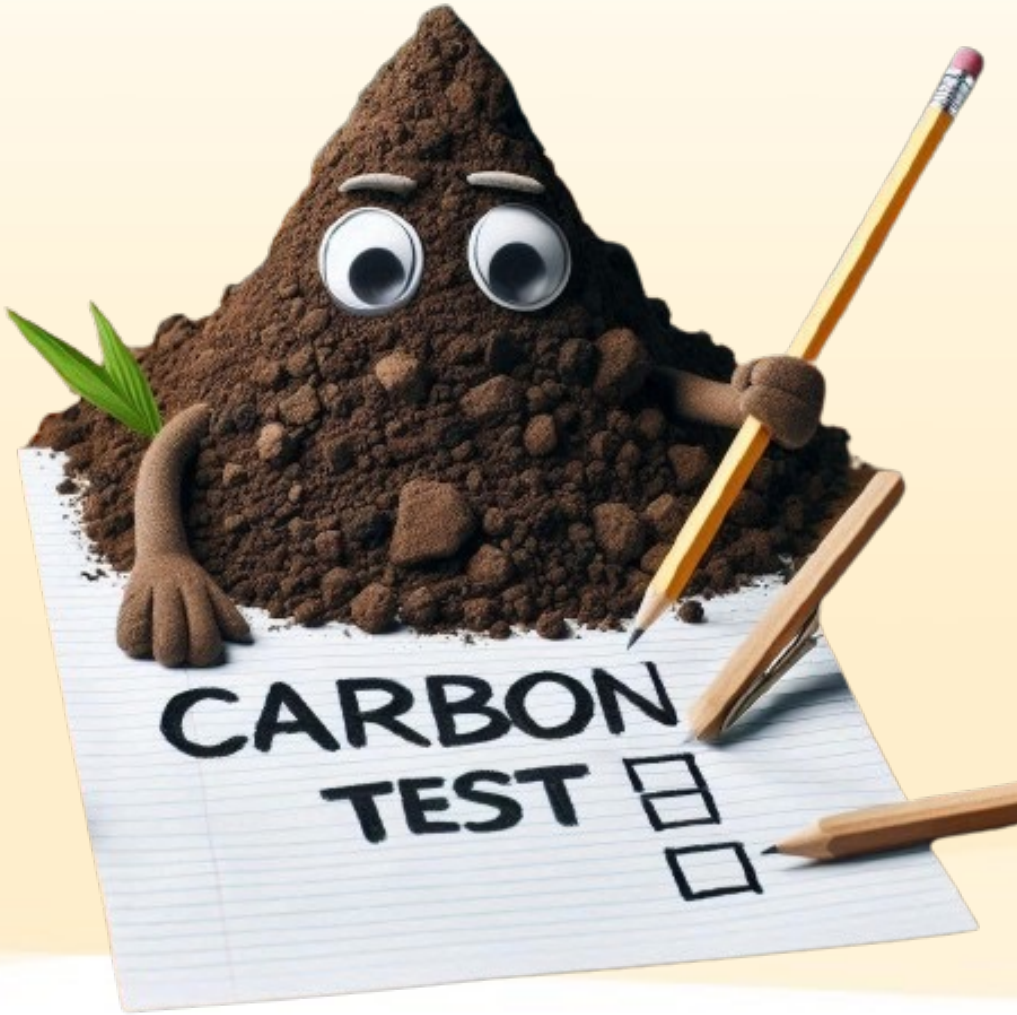
Soil Testing Methods for Carbon

- When testing for carbon in soil, you can do so directly or indirectly
- Direct sampling requires soil sampling at different depths at regular intervals of time
- Indirect sampling focuses on the activity of microbial communities in the soil
- These are **not substitutable** but answer different questions about your soil carbon



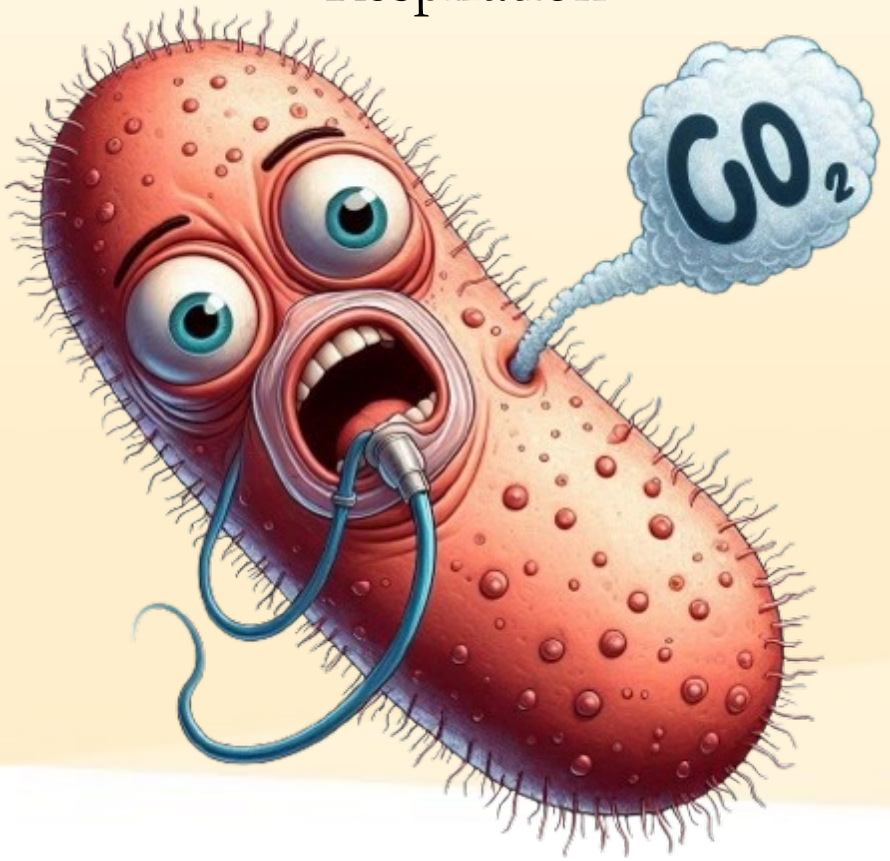
Soil Biological Indicators

Microbial Respiration (CO_2):

- The amount of carbon dioxide released by microbes

- An indicator of activity

Carbon Loss via Heterotrophic Respiration



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(Dynarski et al. 2020)

Soil Biological Indicators

Microbial Respiration (CO_2):

- Lab Analysis (~$30 per sample, plus cost of overnight shipping)

  (or)

- In the Field via Solvita Test Kit with 8 CO2 probes ($~110, plus additional refills)

(Solvita Test Kit is shown as an example, not an endorsement)

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Soil Biological Indicators

Microbial Respiration (CO_2):

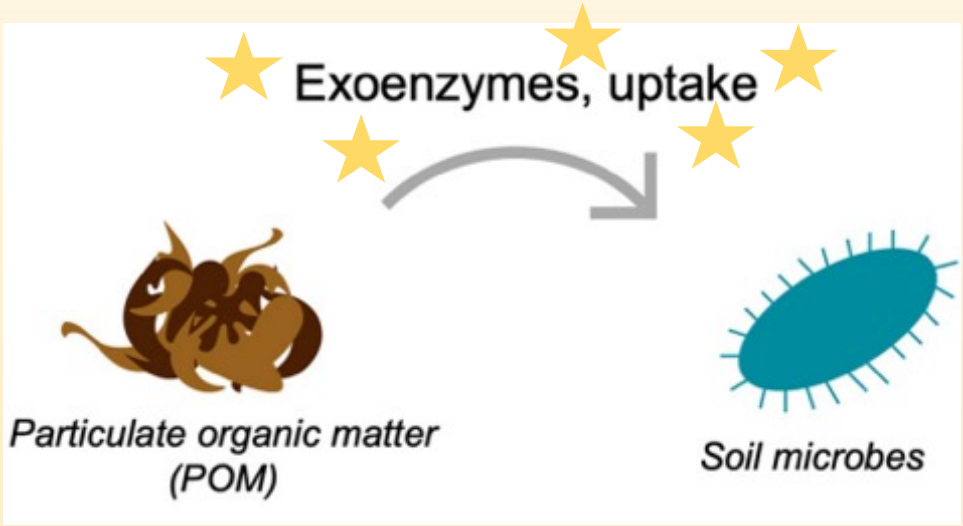
- Lab Analysis
  - Less work
  - More precise

- In the Field via Solvita Test Kit
  - More work
  - Less precise
  - Could be a good educational tool

Soil Biological Indicators

Enzyme Activity: (~$30 per sample per enzyme)

- An indicator of activity, analyzed in a lab
- Microbial proteins that accelerate chemical reactions & aid in decomposition
- Enzyme examples:
  - β-glucosidase (BG): Carbon Cycle
  - N-Acetyl-β-glucosaminidase (NAG): Nitrogen Cycle

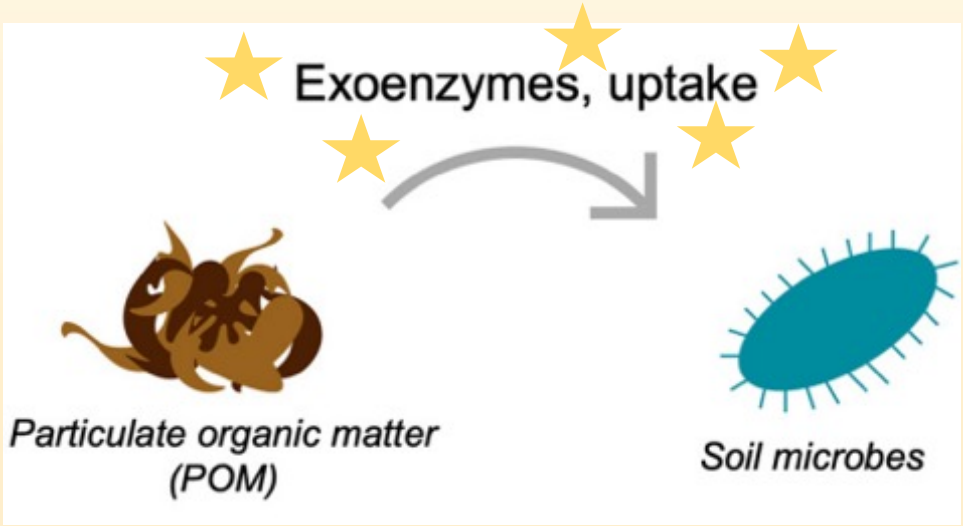


(Dynarski et al. 2020)

Soil Biological Indicators

Enzyme Activity: (~$30 per sample per enzyme)

- Provides information about specific microbial activities & functions
- Could just measure soil C and N status instead of enzymes that cycle C & N
- Could be an interesting educational tool



(Dynarski et al. 2020)

Forms of Carbon in the Soil

- Soil Organic Carbon (**SOC**)
  - Carbon component of organic compounds in the soil
- Total Organic Carbon (**TOC**)
  - Same thing as SOC
- Soil Organic Matter (**SOM**)
  - Any material originally produced by living organisms (includes carbon + other stuff like nitrogen)

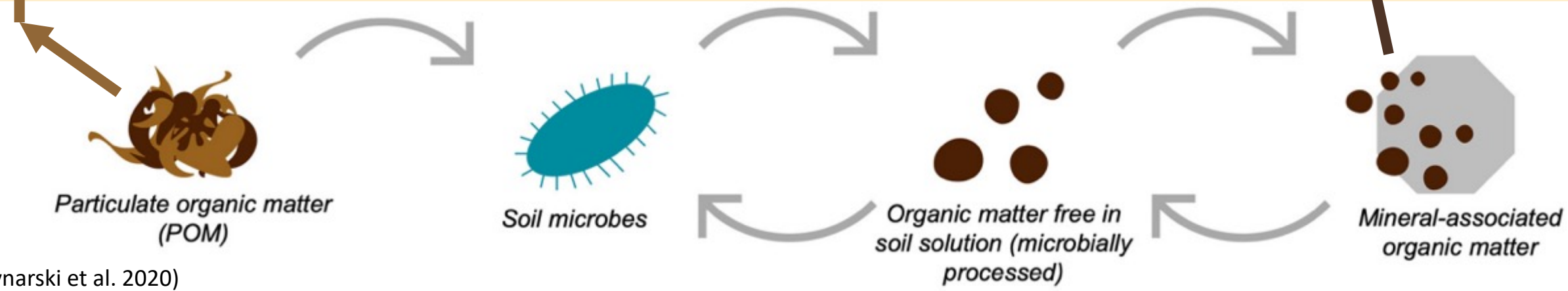
Forms of Carbon in the Soil

- Total Carbon (**TC**)
  - Both organic & inorganic C
- Active Carbon
  - The portion of SOM actively involved in nutrient cycling
- Permanganate oxidizable carbon (**POX-C**)
  - The labile carbon in the soil
- Water Extractable Organic Carbon (**WEOC**)
  - The organic carbon that's readily available to microbes

Forms of Carbon in the Soil

- Particulate Organic Matter (**POM**):
  - Somewhat broken-down SOM

- Mineral-Associated Organic Matter (**MAOM**):
  - Smaller molecular weight, microbially processed compounds that are stuck to the surfaces of mineral particles (more stable)



(Dynarski et al. 2020)

Forms of Soil Carbon

- Soil Organic Carbon (**SOC**) & Total Organic Carbon (**TOC**)
  - Carbon in organic compounds in the soil
- Soil Organic Matter (**SOM**)
  - Produced by living organisms
- Total Carbon (**TC**)
  - Both organic and inorganic carbon
- Permanganate oxidizable carbon (**POX-C**)
  - Labile (easily or frequently changed) carbon in the soil
- Water Extractable Organic Carbon (**WEOC**)
  - Carbon available to microbes
- Particulate Organic Matter (**POM**)
  - Partially broken-down SOM
- Mineral-Associated Organic Matter (**MAOM**)
  - OM stuck to mineral surfaces
- Microbial Biomass Carbon
  - Carbon that comes from the bodies of soil microbes

Lab Analysis

Soil Organic Matter (SOM) via lab analysis

- Least expensive, most common
- Most widely applicable way for farmers to assess soil carbon
- You can add it on to most soil fertility tests

Haney Soil Test

- The Haney Soil Test measures soil biological health through measurements of nutrient availability and microbial activity

- Measures:
  1. Plant-available nutrients
  2. Soil microbial respiration
  3. Water-soluble fractions of organic carbon and nitrogen

- Answers the questions:
  1. What is the current condition of my soil?
  2. Is my soil in balance?
  3. Can I improve my soil and how?

Haney Soil Test

Haney Test focuses on nutrients available to microbes & includes:

- Soil respiration
- Water extractable organic carbon
- Microbially Active Carbon
- Water Extractable Organic Nitrogen
- Organic C to Organic N Ratio
- Organic N to Inorganic N Ratio
- Organic N Release
- Organic N Reserve
- Soil Health Score – but this only pertains to the listed indicators

General Sampling Guidelines

Be systematic & consistent:

- Collect samples when soil moisture is moderate--not soggy, not too dry
- Collect **all soil samples on the same day**
- **Be consistent** with how you collect samples & use field equipment

General Testing Guidelines

Be systematic & consistent:

- Collect **soil samples ideally once/year** at the **same time of year**
- Send to the **same lab** each year
- Always check first to make sure the lab you're sending samples to offers the specific services you want

Soil Health

- One of the most complex environmental factors we can influence directly

- Comprised of many measures:
  1. Soil structure
  2. Soil Organic Carbon (SOC)
  3. Chemical properties
  4. Nutrient and water retention
  5. Many more
  6. Soil texture

Practices for Improving Soil Health

There are many practices that are implemented with the goal of improving soil health

Today, we'll focus on a handful:

- Organic Matter Amendments
- Cover Crops
- Soil Disturbance
- Livestock Integration

Examples of Soil Health Practices

- Applying organic matter amendments such as compost, mulch, etc.
- Keeping living roots in the soil, such as cover crops
- Minimizing soil disturbance
- Livestock integration

Examples of Soil Health Practices

Always start with a quick **cost analysis** to see which practices pencil out for you

Consider the frequency, location, application rates, etc. and associated costs

Every farm is different: do what makes sense for your unique context, goals, constraints, opportunities

Organic Matter Amendments

- Organic matter amendments are most often in the form of:
  - Mulch
  - Compost
  - Manure
- Improves soil structure and microbial health and activity
- Directly adds organic carbon to the soil system

Organic Matter Amendments & Microbes

- Lower carbon to nitrogen ratio (C:N) means microbes have more nitrogen
- Compost will have lower C:N than mulch
- Can use more than one type of organic matter amendments

Recent Findings – Organic Amendments

- Long-term studies provide highest resolution conclusions
- Long-term application of organic amendments changes microbial activity in soils over long periods (years)
  - But does not change total GHG emissions from the soil
  - N_2O can increase via nitrification but so does denitrification
- Impacts will depend on the **type** of OM applied and the **soil management practices** employed on site
  - Tillage + Manure + Biochar = Decreased GHG emissions
  - Tillage alone = Increased GHG emissions

Recent Findings – Organic Amendments

- Organic amendments can also restore a degraded soil
- Compost application has been shown to increase
  - Water content
  - Available Nitrogen
  - SOM
  - Microbial biomass/activity
- In grapevines, these changes in soil properties have led to:
  - Improved Yield
  - Higher YANs
  - Increased Titratable Acidity
  - But decreased TSS (°Brix)
- Impacts are climate-dependent
  - Soil organic carbon sequestration from amendments may decrease at high temperatures and under drought conditions

Recent Findings – Organic Amendments

Calleja-Cervantes, M. E., Fernández-González, A. J., Irigoyen, I., Fernández-López, M., Aparicio-Tejo, P. M., & Menéndez, S. (**2015**). Thirteen years of continued application of composted organic wastes in a vineyard modify soil quality characteristics. *Soil Biology and Biochemistry*, *90*, 241-254. https://doi.org/https://doi.org/10.1016/j.soilbio.2015.07.002

Horel, Á., Tóth, E., Gelybó, G., Dencső, M., & Potyó, I. (**2018**). Soil CO2 and N2O Emission Drivers in a Vineyard (Vitis vinifera) under Different Soil Management Systems and Amendments. *Sustainability*, *10*(6), 1811. https://www.mdpi.com/2071-1050/10/6/1811

Mondini, C., Fornasier, F., Sinicco, T., Sivilotti, P., Gaiotti, F., & Mosetti, D. (**2018**). Organic amendment effectively recovers soil functionality in degraded vineyards. *European Journal of Agronomy*, *101*, 210-221. https://doi.org/https://doi.org/10.1016/j.eja.2018.10.002

Payen, F. T., Sykes, A., Aitkenhead, M., Alexander, P., Moran, D., & MacLeod, M. (**2021**). Soil organic carbon sequestration rates in vineyard agroecosystems under different soil management practices: A meta-analysis. *Journal of Cleaner Production*, *290*, 125736. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.125736

Cover Crops

- Provide living root tissue, resources for microbes, and organic exudates
- Over time, cover crops can increase soil carbon levels via microbial health
- Cover crops can also increase soil organic matter by limiting soil surface erosion and adding biomass to the soil via roots and aboveground tissue
- Cover crops can increase soil organic matter by up to 114%

Recent Findings – Cover Crops

- Cover crops have been shown to directly improve water use efficiency in vineyard soils
  - Cover Crops lead to reduced runoff & increased soil water storage (+27%)
  - This allows roots to grow deeper and vines to be more vigorous
- Under-Vine/Plant cover cropping improves most soil-health parameters, quickly
  - Higher SOC, POC, and Soil Aggregation
  - Increased microbial activity (≈ 18% increase – gas)
  - Improves soil physical, chemical, and biological properties

Recent Findings – Cover Crops

- Impacts of cover crops depends heavily on seasonal conditions
  - Soil carbon dynamics and CO_2 efflux (outflow) are sensitive to seasonal changes, especially in water content; wet soil = higher CO_2 efflux

- Cover crops in table grape vineyards increases some measures of soil health and carbon content

  SOC = + 136% Microbial Biomass C = + 112% Total N = +93%

- Nutrient cycling in soil may also improve with cover crop applications

  β-glucosidase = + 100% APME = + 62%

Recent Findings – Cover Crops

Abad, F. J., Marín, D., Imbert, B., Virto, I., Garbisu, C., & Santesteban, L. G. (**2023**). Under-vine cover crops: Impact on physical and biological soil proprieties in an irrigated Mediterranean vineyard. *Scientia Horticulturae*, *311*, 111797. https://doi.org/https://doi.org/10.1016/j.scienta.2022.111797

Gattullo, C. E., Mezzapesa, G. N., Stellacci, A. M., Ferrara, G., Occhiogrosso, G., Petrelli, G., Castellini, M., & Spagnuolo, M. (**2020**). Cover Crop for a Sustainable Viticulture: Effects on Soil Properties and Table Grape Production. *Agronomy*, *10*(9), 1334. https://www.mdpi.com/2073-4395/10/9/1334

Novara, A., Cerda, A., Barone, E., & Gristina, L. (**2021**). Cover crop management and water conservation in vineyard and olive orchards. *Soil and Tillage Research*, *208*, 104896. https://doi.org/https://doi.org/10.1016/j.still.2020.104896

Steenwerth, K., & Belina, K. M. (**2008**). Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied Soil Ecology*, *40*(2), 359-369. https://doi.org/https://doi.org/10.1016/j.apsoil.2008.06.006

Soil Disturbance

- Soil disturbance includes many aspects
  - Erosion
  - Compaction
  - Amendments / Fertilization
  - Irrigation / Precipitation
- Tillage
  - Maybe the most impactful soil disturbance
  - Often applied annually
- All of these can impact soil ~ carbon dynamics

Recent Findings – Till/No-Till

- No-Till practices in vineyards can increase SOC by 8% over 5-10 years
  - No-tilled sites with cover crops can sequester ≥ 1 metric ton of CO_2 per hectare per year following proper establishment timeframes
- Spring emissions of GHG from microbial activity increases with tillage during periods where soils are wet
- Long-term soil conservation practice studies almost always have shown overall increases in SOM and SOC **when paired with cover crops**
  - On **bare soil**, tillage has little to no impact on annual C budgets
  - CO_2 emissions increase immediately after tillage, but return to pre-tillage soil respiration values after a few days

Recent Findings – Till/No-Till

- Soil CO_2 fluxes are sensitive to soil temperatures, which are less stable in recently tilled soils – Soil Thermal Regime
  - Net Carbon uptake in vineyards can be 45% higher in no-tilled soils

- Many factors influence soil carbon storage and a vineyard's C-balance, but may act as a carbon sink if properly managed
  - Soil physical and chemical characteristics
  - Grapevine biological properties (root system can account for 26% c-storage)
  - Ground management techniques

Recent Findings – Till/No-Till

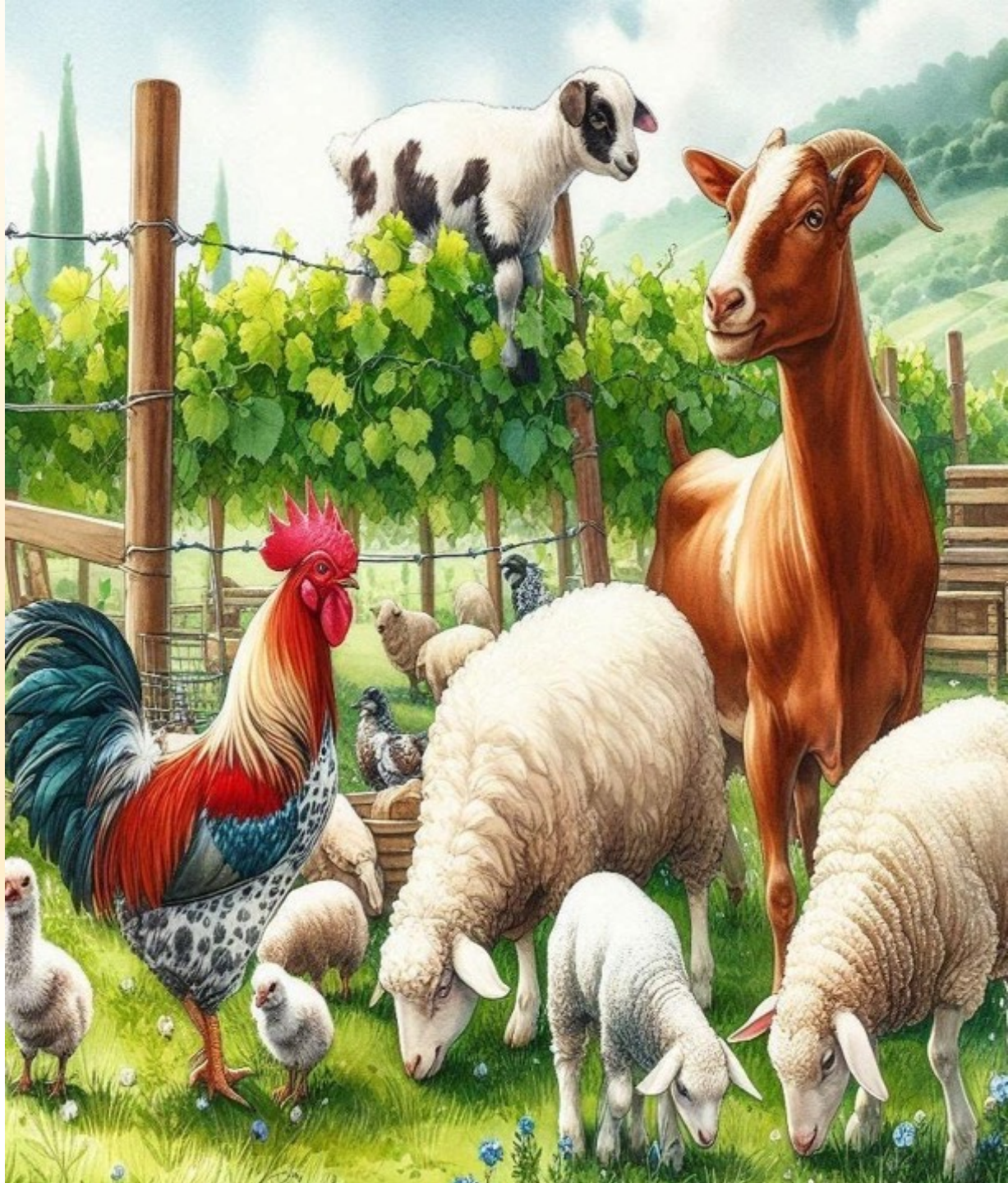
Brunori, E., Farina, R., & Biasi, R. (2016). Sustainable viticulture: The carbon-sink function of the vineyard agro-ecosystem. *Agriculture, Ecosystems & Environment*, *223*, 10-21. https://doi.org/https://doi.org/10.1016/j.agee.2016.02.012

Tezza, L., Vendrame, N., & Pitacco, A. (2019). Disentangling the carbon budget of a vineyard: The role of soil management. *Agriculture, Ecosystems & Environment*, *272*, 52-62. https://doi.org/https://doi.org/10.1016/j.agee.2018.11.002

Wolff, M. W., Alsina, M. M., Stockert, C. M., Khalsa, S. D. S., & Smart, D. R. (2018). Minimum tillage of a cover crop lowers net GWP and sequesters soil carbon in a California vineyard. *Soil and Tillage Research*, *175*, 244-254. https://doi.org/https://doi.org/10.1016/j.still.2017.06.003

Livestock Integration

- Multiple attempts at integrating livestock have been attempted:
  - Cows = No
    - Damage infrastructure
  - Goats = No-ish
    - Eat the crop plant (and infrastructure)
  - Chickens = Kind of
    - Require regular or daily rotation
  - **Sheep = YES**
    - Require semi-regular rotation
    - Don't often eat the crop plant
    - Can be trained for ideal grazing habits



Recent Findings – Livestock Integration

- Large livestock grazing in agricultural systems has recently been shown to
  - Improve subsoil organic carbon storage in the soil
  - Stimulate soil carbon flux
  - Increase quantity of active, labile, and soluble carbon in soil
- These impacts were shown under **high-density, short-duration, rotational grazing**
- Soil carbon outcomes from grazing are influenced by the timing and frequency of the grazing events and site conditions

Recent Findings – Livestock Integration

- Over short periods of time (7-10 days) after grazing events in spring:
  - Sheep grazing does not increase available soil N or C
  - Results in localized, daily peaks in N_2O, CH_4, and CO_2 emissions
  - Whole-year emissions are not significantly larger than in ungrazed soils

- Grazing on cover crops has not been shown to lead to short term, undesirable outcomes like yield decrease or negative impacts on fruit composition

Recent Findings – Livestock Integration

Brewer, K. M., Muñoz-Araya, M., Martinez, I., Marshall, K. N., & Gaudin, A. C. M. (2023). Long-term integrated crop-livestock grazing stimulates soil ecosystem carbon flux, increasing subsoil carbon storage in California perennial agroecosystems. *Geoderma*, *438*, 116598. https://doi.org/https://doi.org/10.1016/j.geoderma.2023.116598

Lazcano, C., Gonzalez-Maldonado, N., Yao, E. H., Wong, C. T. F., Merrilees, J. J., Falcone, M., Peterson, J. D., Casassa, L. F., & Decock, C. (2022). Sheep grazing as a strategy to manage cover crops in Mediterranean vineyards: Short-term effects on soil C, N and greenhouse gas (N2O, CH4, CO2) emissions. *Agriculture, Ecosystems & Environment*, *327*, 107825. https://doi.org/https://doi.org/10.1016/j.agee.2021.107825

Ryschawy, J., Tiffany, S., Gaudin, A., Niles, M. T., & Garrett, R. D. (2021). Moving niche agroecological initiatives to the mainstream: A case-study of sheep-vineyard integration in California. *Land Use Policy*, *109*, 105680. https://doi.org/https://doi.org/10.1016/j.landusepol.2021.105680

Recent Findings – Stacking Practices

Tillage and Organic Amendments

- Tillage alone has been shown to increase GHG emissions and degrade soil structure
- In conjunction with Manure or Biochar applications, tillage can help improve soil microbial activity and increase denitrification in the soil

Tillage and Cover Crops

- Minimum tillage in conjunction with cover cropping can offset GHG emissions through higher CO_2 offsets of CH_4 and N_2O via carbon sequestration

Recent Findings – Stacking Practices

Cover Crops and Livestock Integration

- Livestock integration almost **requires** cover cropping practices are being implemented on site
- Utilizing livestock and cover cropping practices can increase the flux of carbon within the agricultural system
- May also increase the total carbon stored in the soil over long-periods of time

Recent Findings – Stacking Practices

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