Overview of management tools to improve soil carbon and reduce N inputs

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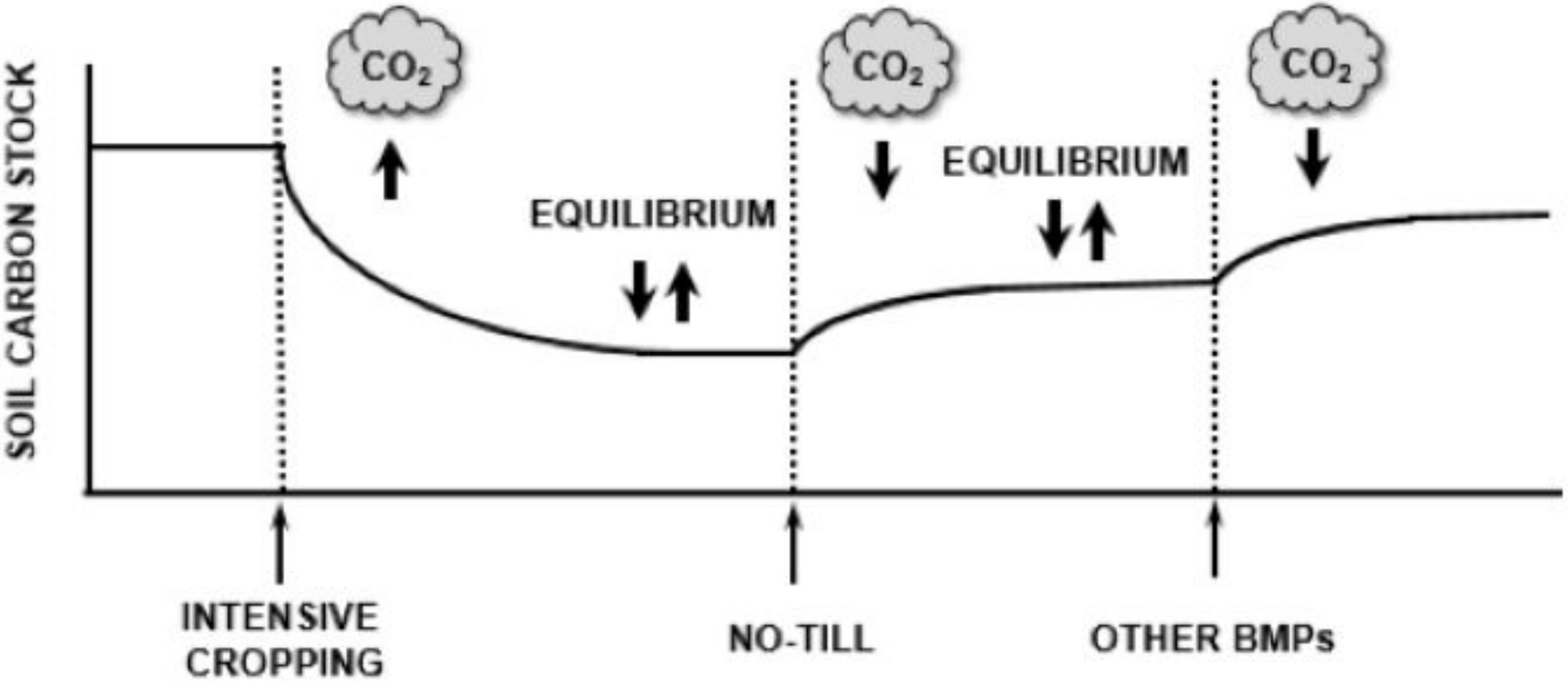
Agriculture and agri-food sector transformation

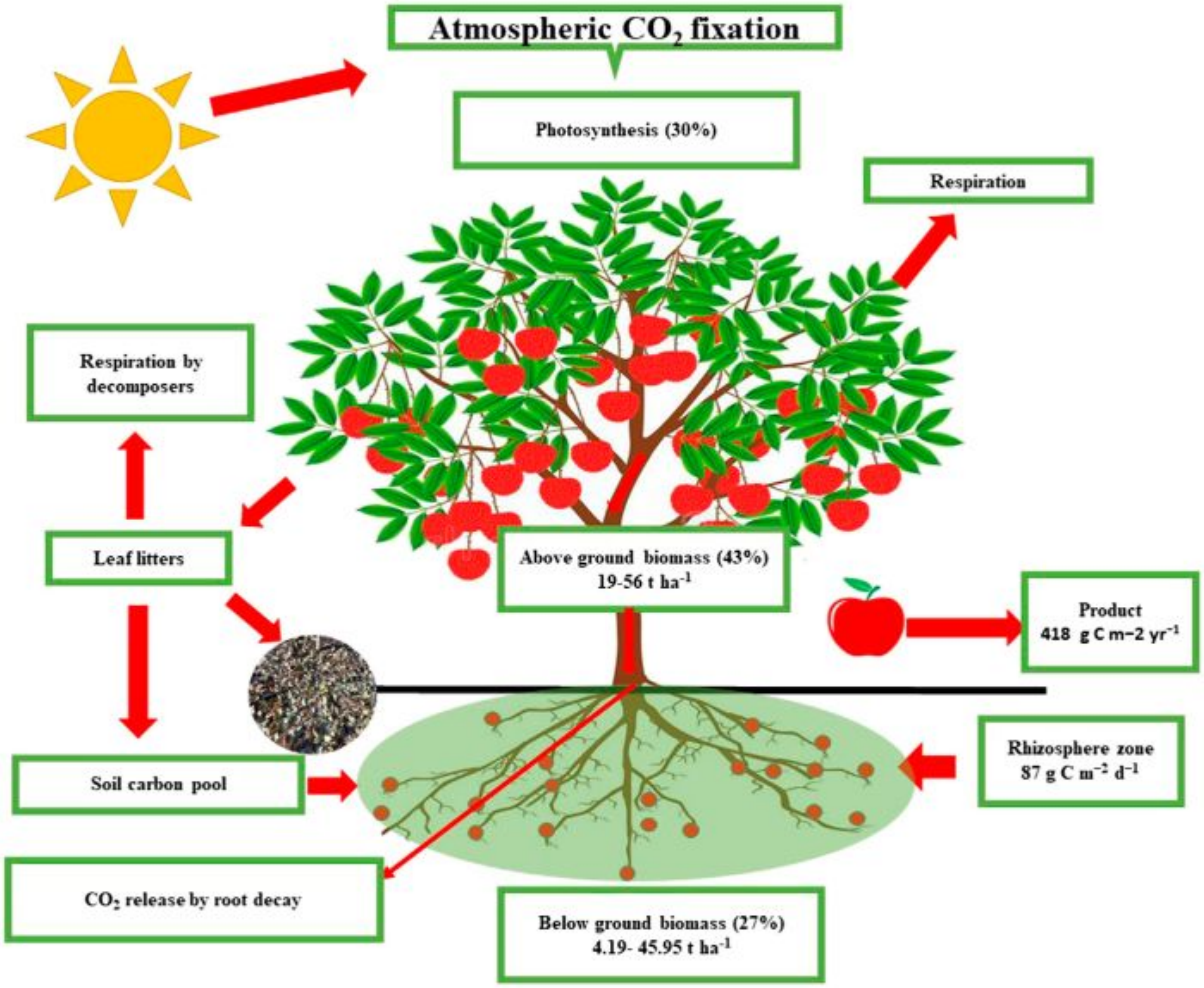
- The world is facing major challenges as they relate to climate change, food security, and resources conservation;
- A rethinking and transformation of our production systems for long-term sustainability is required;
- The change begins with a paradigm shift toward sustainable agriculture, which takes into consideration the environmental, social, and economic context.

A restoration company vehicle sits in a flooded field at Abbotsford, B.C. on Nov. 30, 2021. (Photo: Reuters/ Jennifer Gauthier)

Figure 5. Impact of different BMPs on carbon sequestration. Adapted from Fan et al. 2019[29]



Wood-Bohn, 2022. Carbon sequestration in agricultural soils

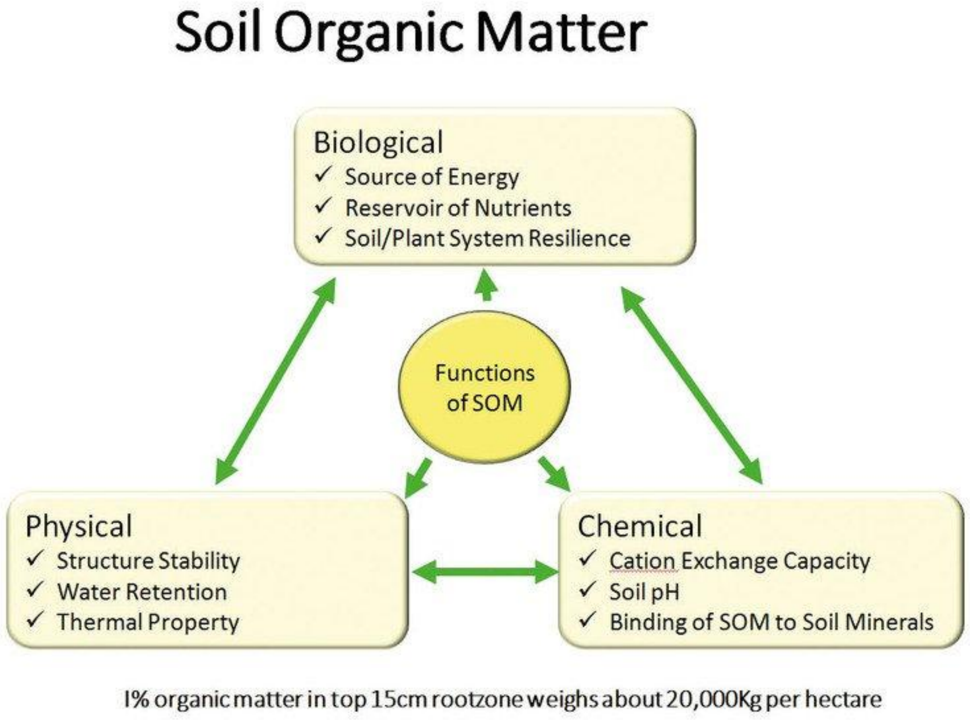


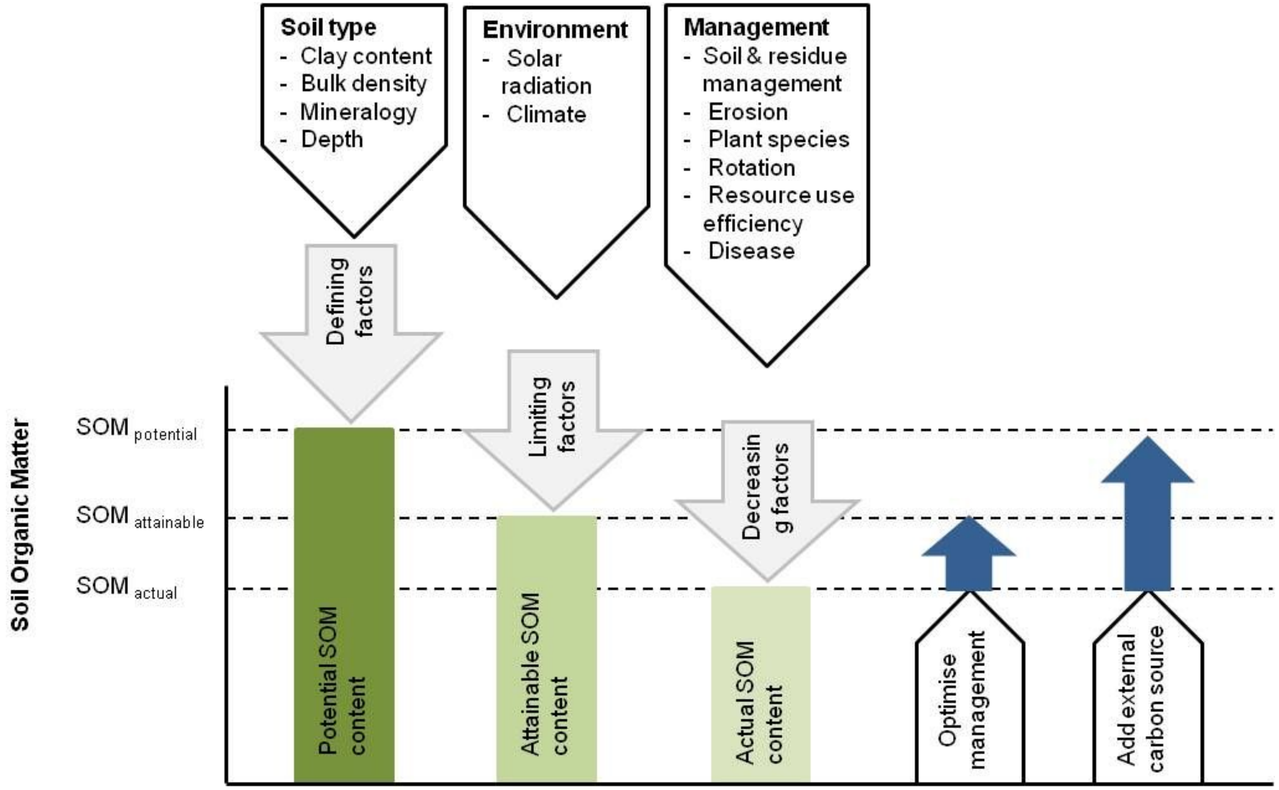
- **Carbon sequestration** is the process of capturing and storing atmospheric carbon dioxide; in this case, carbon is captured and stored by the tree fruit.
- Fruit orchards and vineyards have great structural characteristics, such as long life cycle; permanent organs such as trunk, branches, and roots; null soil tillage, which allow them to accumulate a significant amount of carbon (Sharma et al. 2021).

FIGURE 1 | Schematic diagram of carbon pools in an apple tree (redrawn from Buchmann and Schulze, 1999). The yearly NEP, GPP, and NPP are 403 g Cm^{-2}, 1,346, and 906 g Cm^{-2} $year^{-1}$, respectively. The average NECB indicates significant potential for CO_2 sequestration. OM/OA: organic manures/organic amendment; GPP: gross primary production; NPP: net primary production; NEP: net ecosystem production; NECB: net ecosystem carbon balance; NBP: net biome productivity; RA: autotropic respiration; RH: heterotrophic respiration; Harvest: fruit production; R_{ECO}: ecosystem respiration.

(*Sharma et al.* 2021).

Soil Organic Matter





https://www.pitchcare.com/news-media/soil-organic-matter-is-good.html

https://www.agric.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon

Soil organic carbon fractions and flow

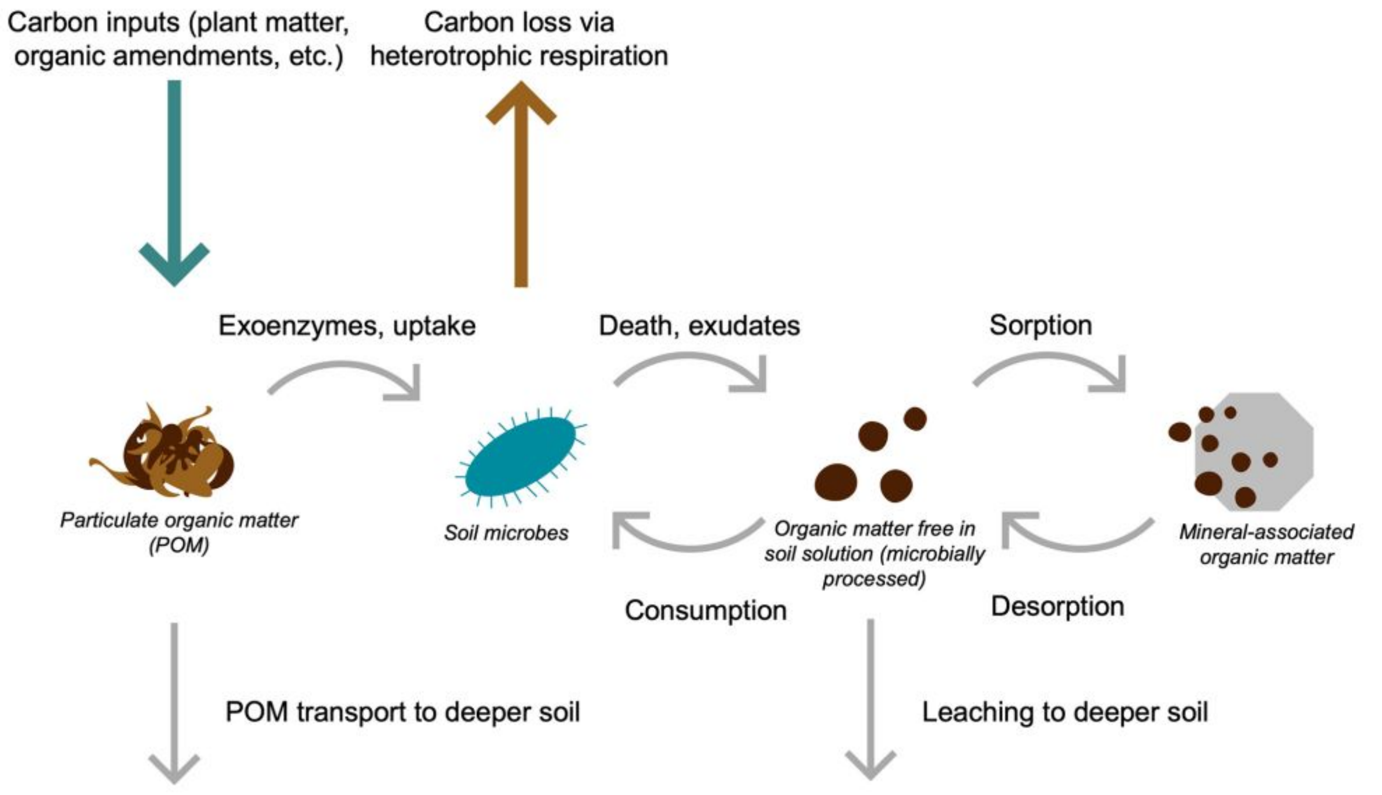
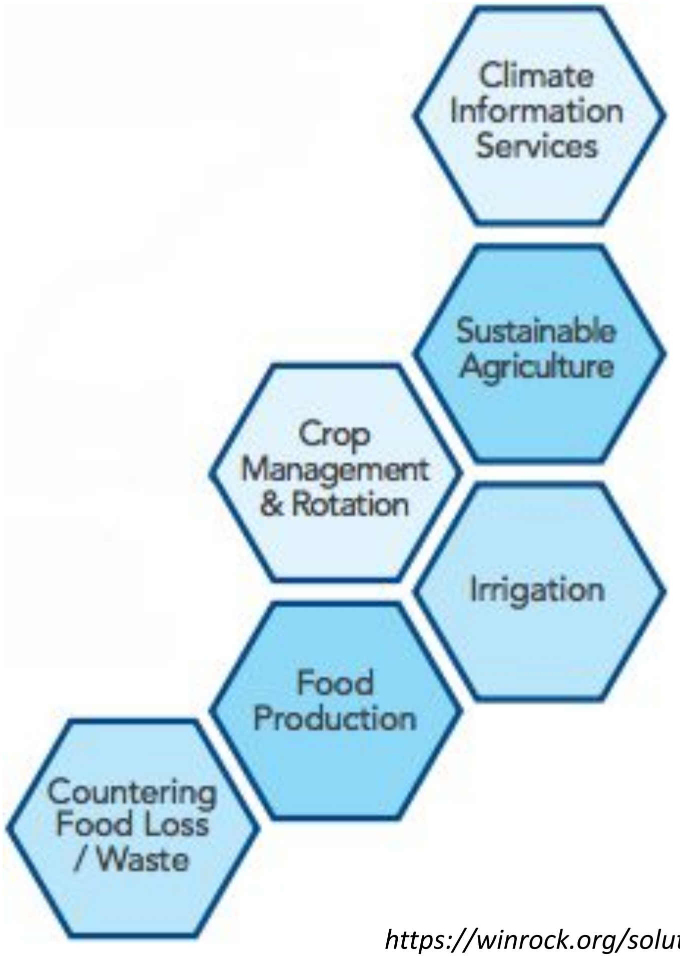


FIGURE 1 | Conceptual illustration of soil carbon (C) flows. Carbon enters soil mainly via plant inputs (green arrow) and is lost via heterotrophic respiration (brown arrow). Plant C inputs are the precursor to particulate organic matter (POM), which can be depolymerized by microbes and taken up into biomass, or transported deeper into the soil profile as particulate matter. Microbial depolymerization, exudation, and turnover releases microbially processed C, which is free in soil solution and can sorb onto mineral surfaces to produce mineral-associated organic matter (MAOM). Mineral-associated organic matter can de-sorb from mineral surfaces and taken back up into microbial biomass or be transported to deeper soil profiles via leaching. Over time, these cycling processes result in the movement of both microbially processed C and POM into increasingly deeper soil horizons.

Dynarski et al. 2020

Carbon sequestration in orchard soils

- **Recycling and import of carbon sources**
  - Pruning or wood residues
  - Organic fertilizers and amendments
- **Increasing biomass delivery**
  - Integrating cover crops
  - Larger root system (*e.g.* rootstock selection, deep-rooted cover crops)
- **Protecting soil carbon (enhance C residence time)**
  - Infrequent conservation-tillage
  - Improved soil structure
  - Biochar and zeolite
  - Reduce soil organic C priming by adjusting input carbon quality
- **Irrigation for carbon farming**
  - Support cover crops
  - Microclimate
  - Reduce losses of dissolved organic carbon and nitrogen
- **Landscape design integrating carbon farming**
  - Stripes for water protection, erosion control and biodiversity
  - Hedge rows, wetlands, ecological corridors and biodiversity islands

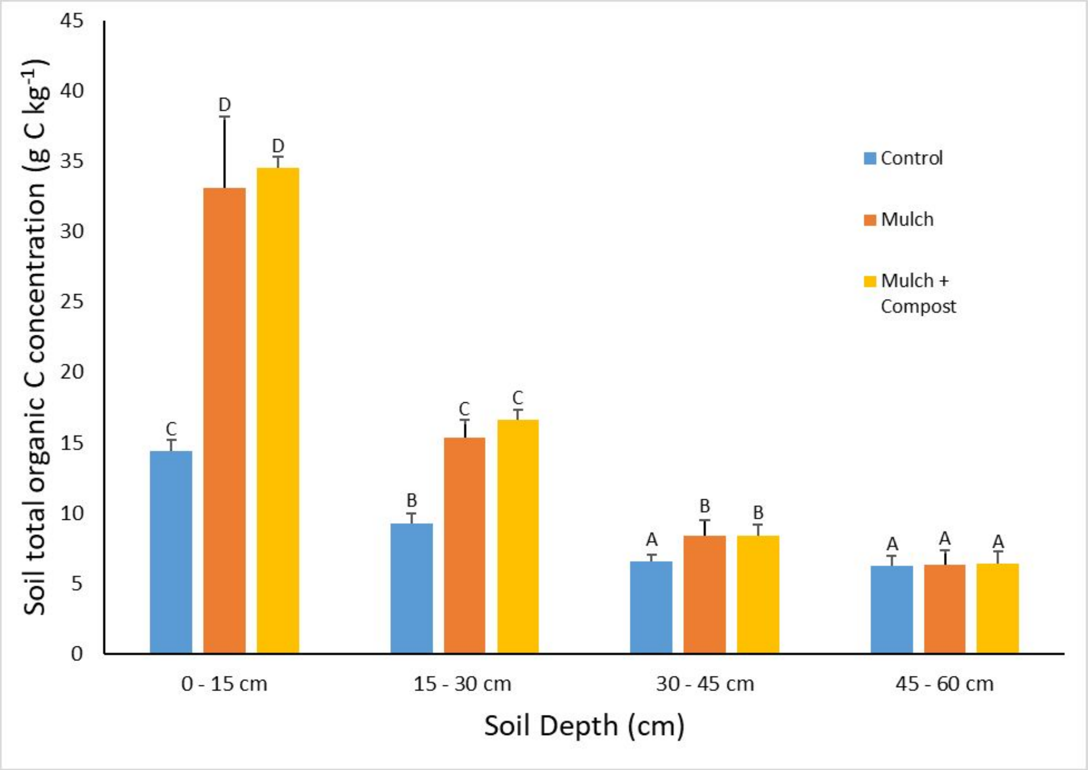


https://winrock.org/solutions

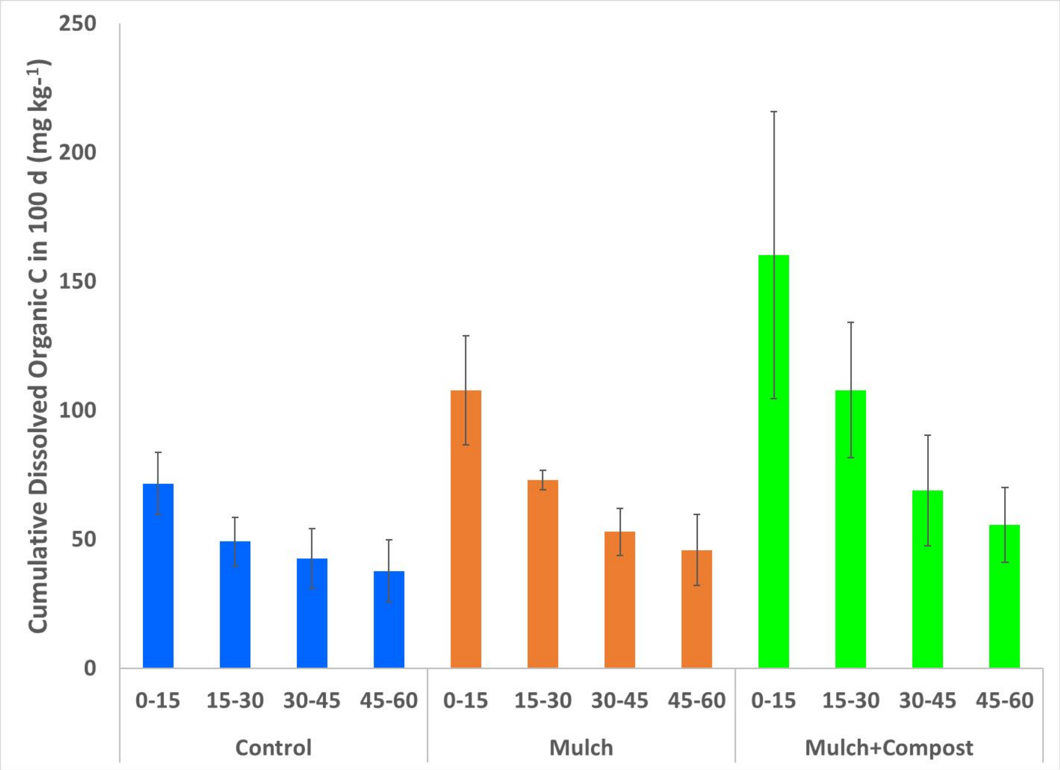
Adopted from Paulsen, 2020. European Union report

Exp 1. Surface applied C-rich material

Amendment X Depth *

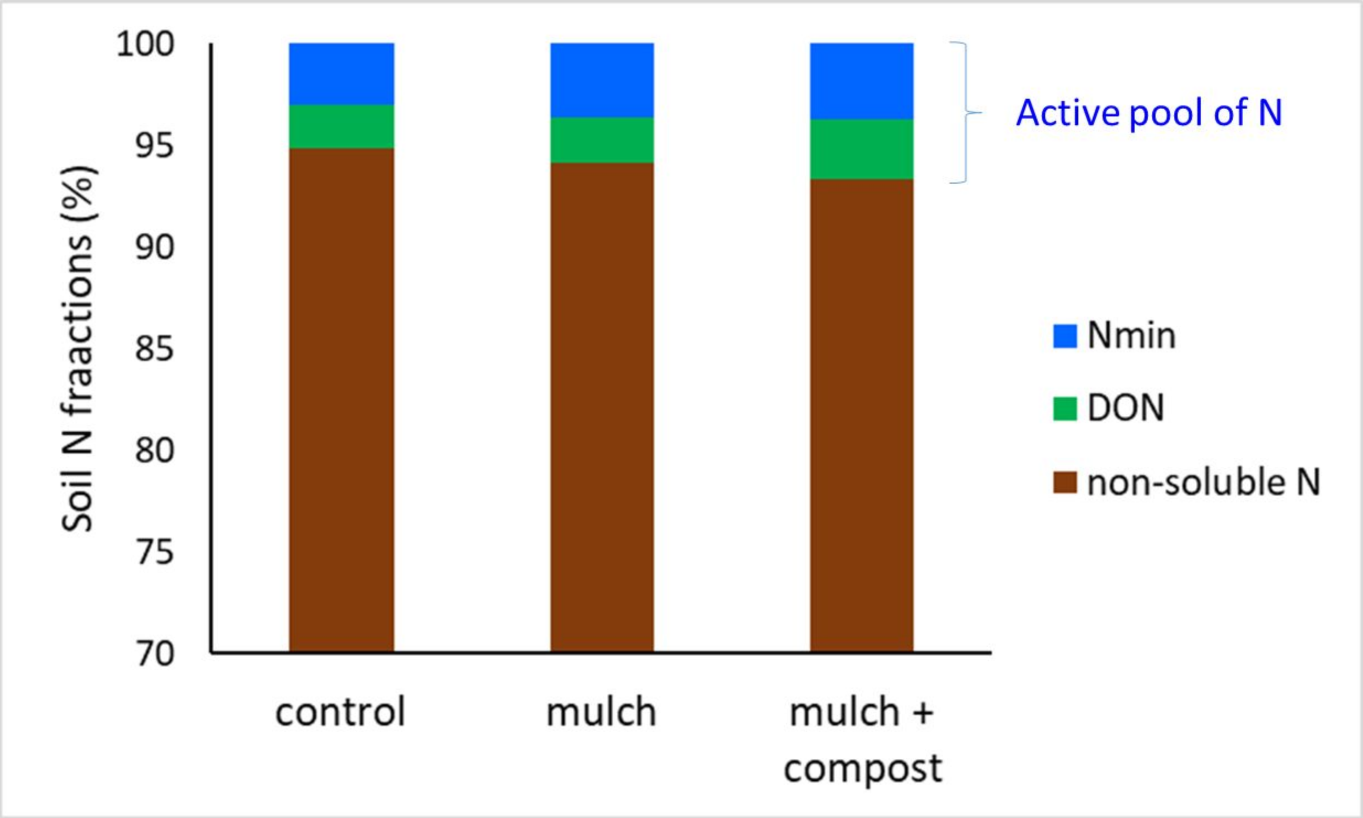


Amendment ***; Depth ***



Total C/DOC ratio= 1750:1

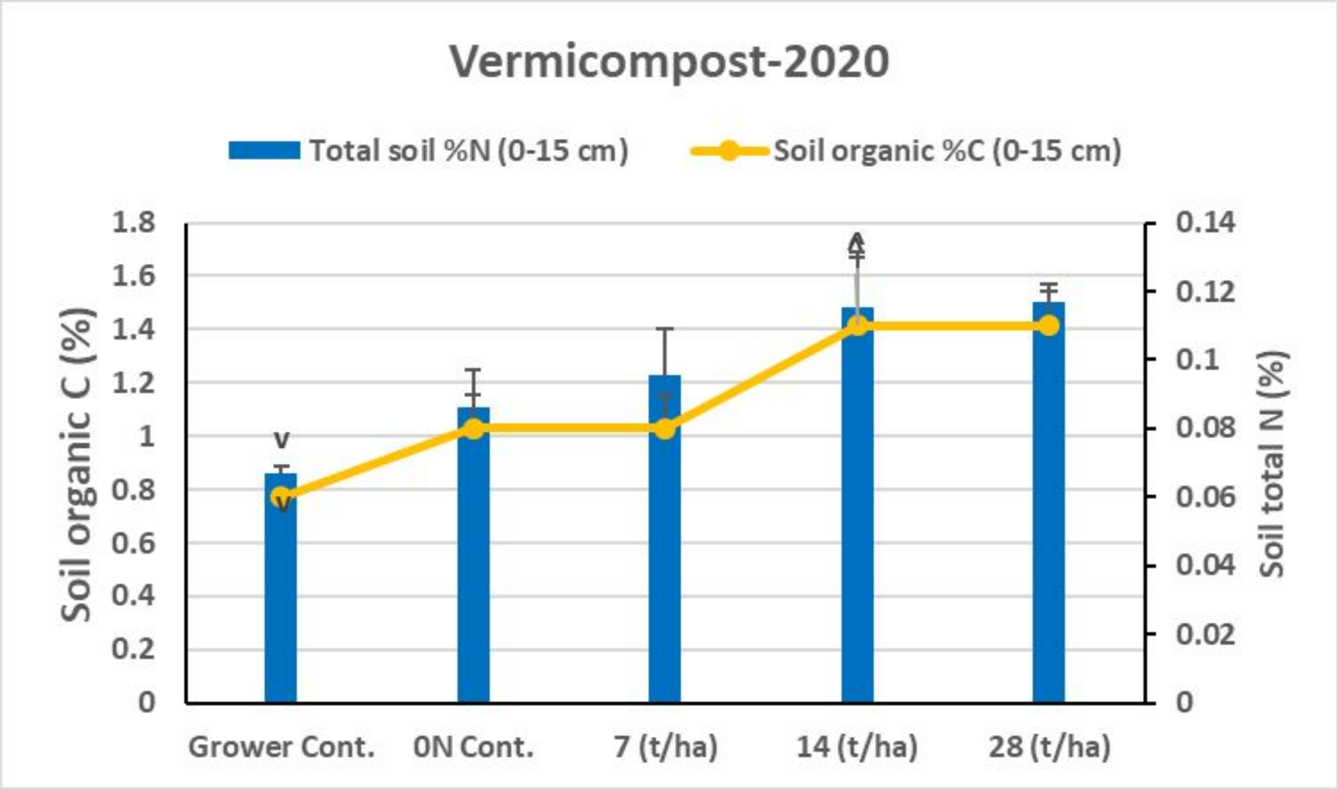
Changes in soil nitrogen fractionations



Quality of soil organic matter was changed by the treatments.

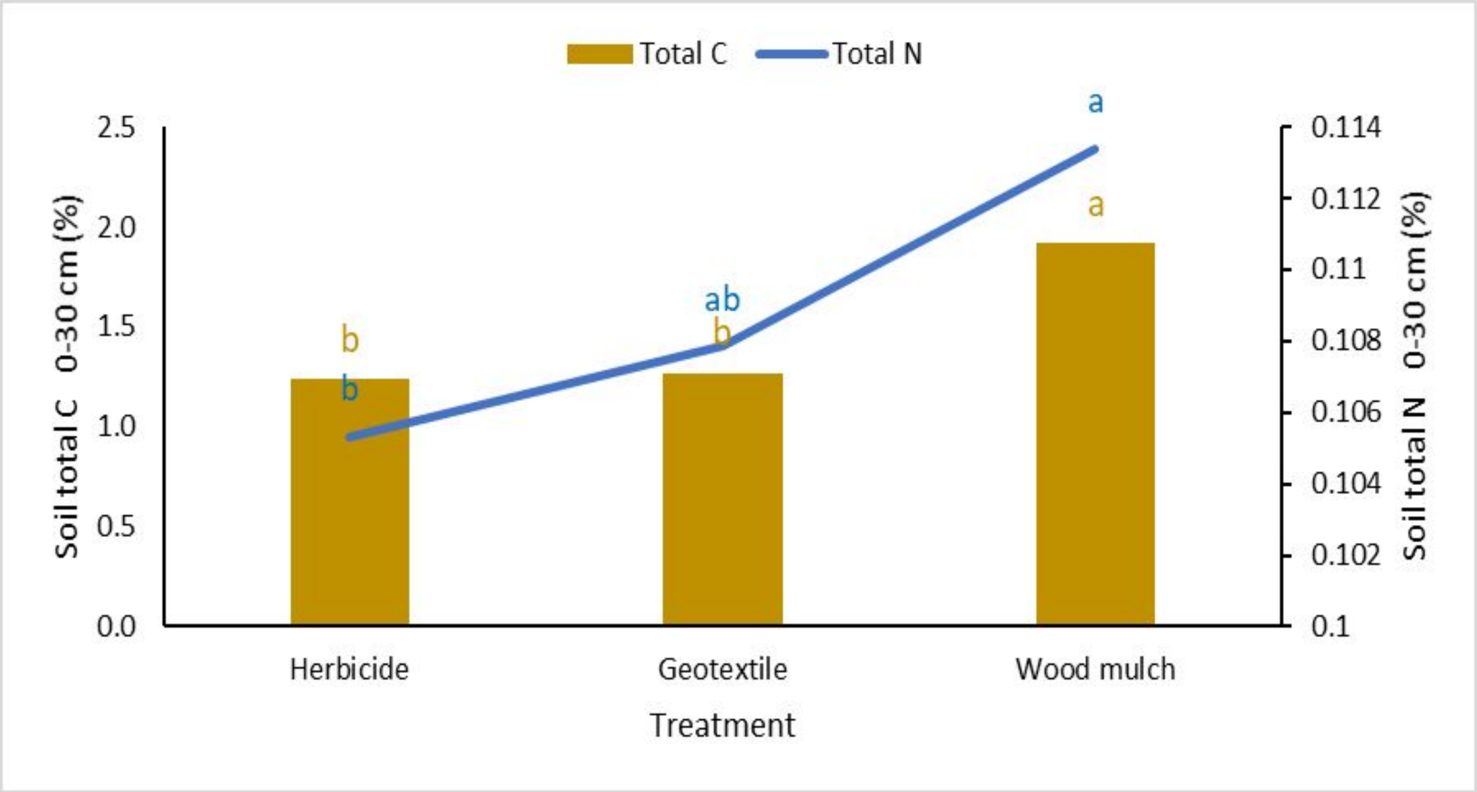
Exp. 2. Vermicompost in a Chardonnay vineyard

[applied in 2018 and 2019]



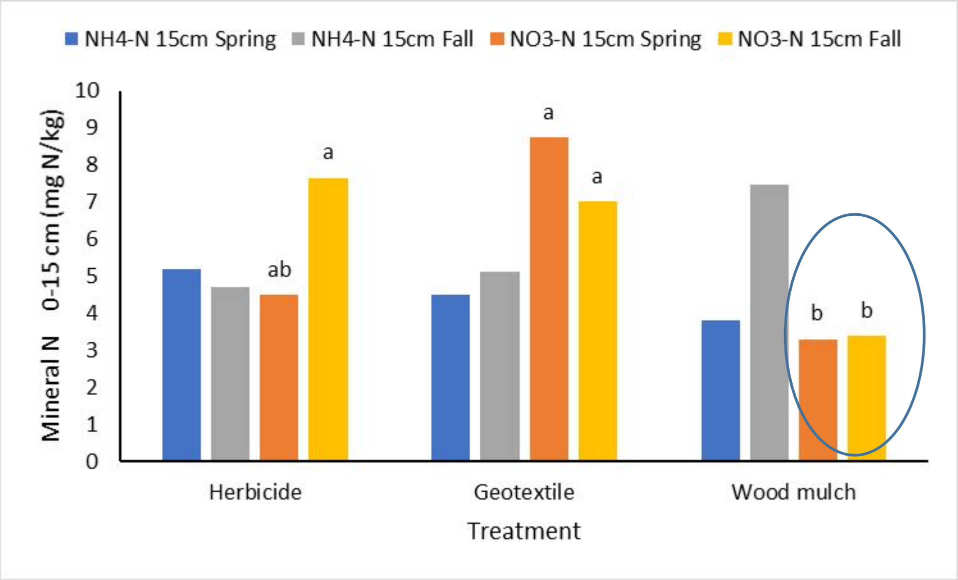
28 ton/ha dry weight

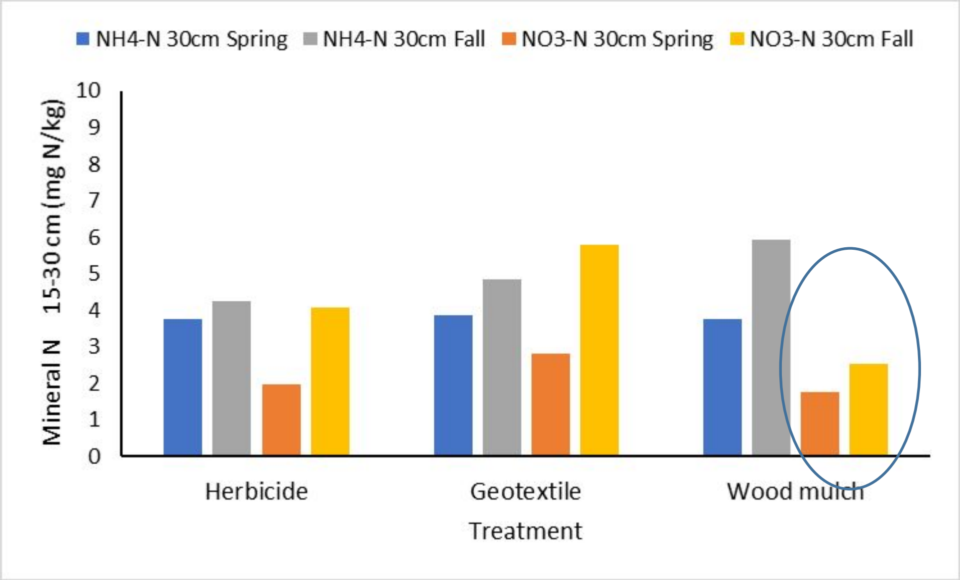
Exp. 3. Soil total C and N (2020)- Sweet Cherry (Lapins on Krymsk 5); applied in 2018 and 2020



2 times increase in soil C and N concentrations by Mulch treatment.

Expr. 3. Soil ammonium and nitrate nitrogen in spring and fall 2021 at depth of 0-15 and 15-30 cm





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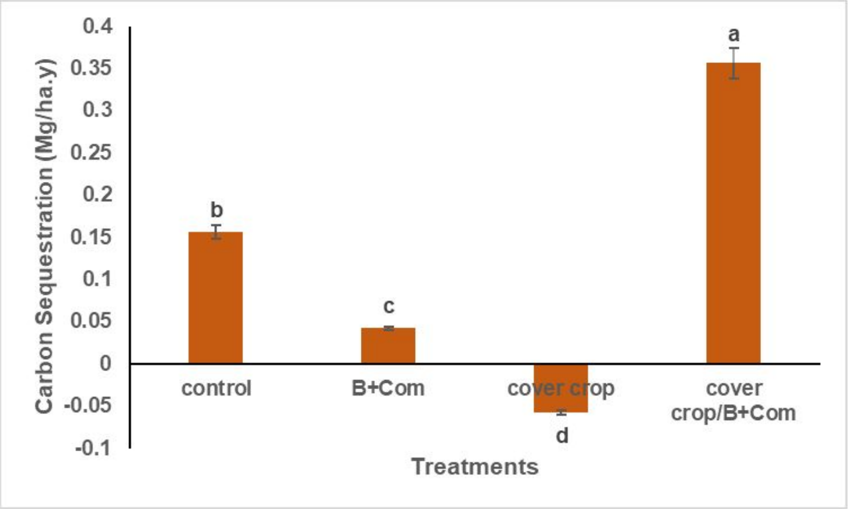
Exp. 4 – Biochar-compost and cover crops

- Same grape block as Exp 1. light soil texture
- Study period: 2017-2020

- Alley treatments:
  - control,
  - Biochar+Compost (B+Com), 1:1 ratio at 22 Mg/ha dry
  - cover crop
  - Cover crop and B+Com



❖ Biochar-compost and cover crop/B+Com increased soil C content averaged across sampling dates by <u>11 and 17%</u> (*P*<0.05) only at the 0-15 cm soil depth compared to the control.

Groundcover Vegetation Management

Cove cropping potential benefits

- Enhance soil health
  - Enhance soil fertility
  - Accelerate C sequestration
  - Increase water holding capacity
  - Reduce nutrient losses
  - Reduce compaction
  - Enhance soil biome diversity and function
- Improve yield and yield quality
- Enhance biodiversity
- Suppress weeds
- Reduce pest and diseases pressure
- Protect against erosion and dust
- Enhance aesthetics

Factor affecting on carbon sequestration by cover crops

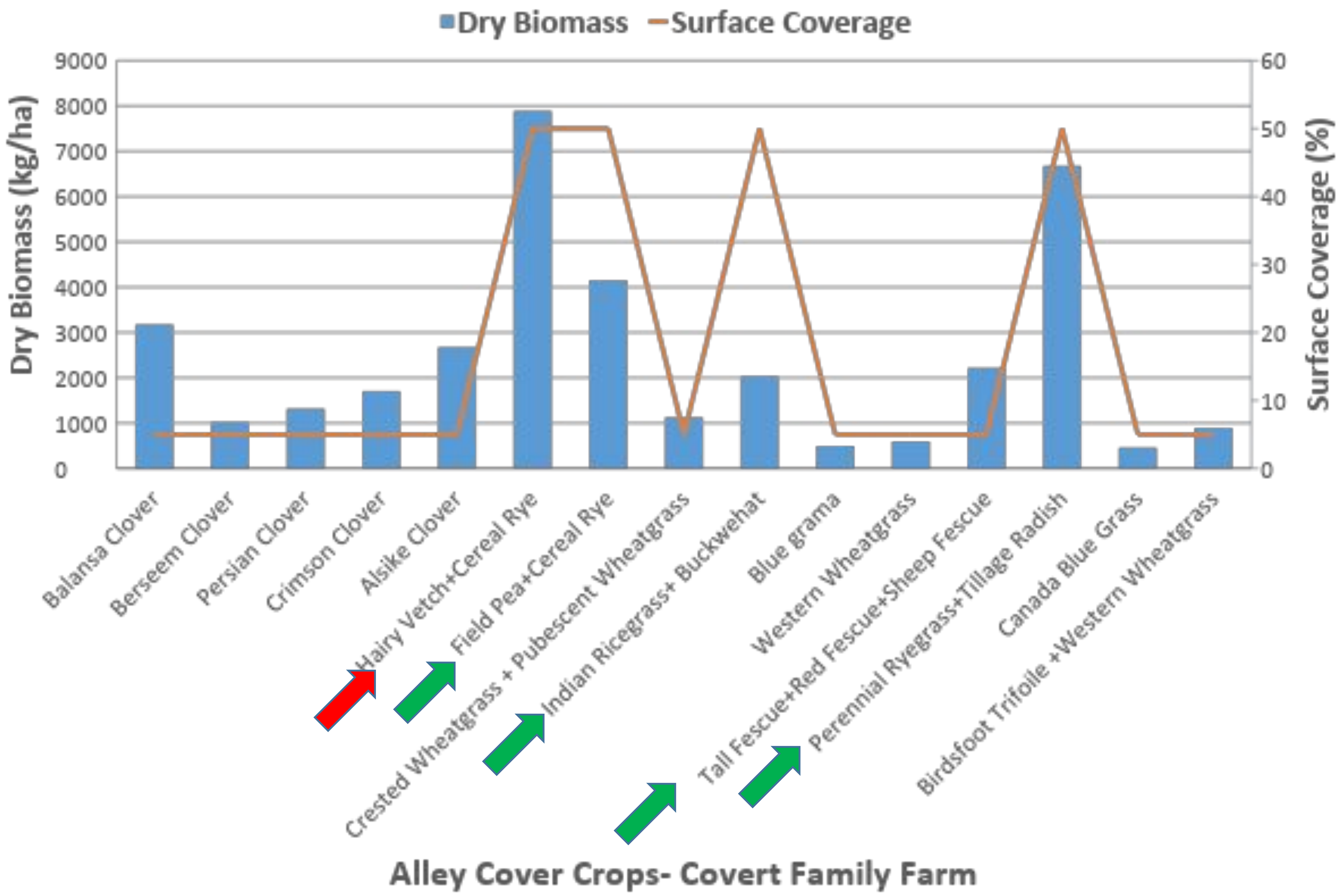
- produced biomass;
- C/N ratio of residues;
- soil depth;
- soil texture;
- rotation cycle;
- main cash crop, and;
- residue management.

Cover crops C sequestration estimates

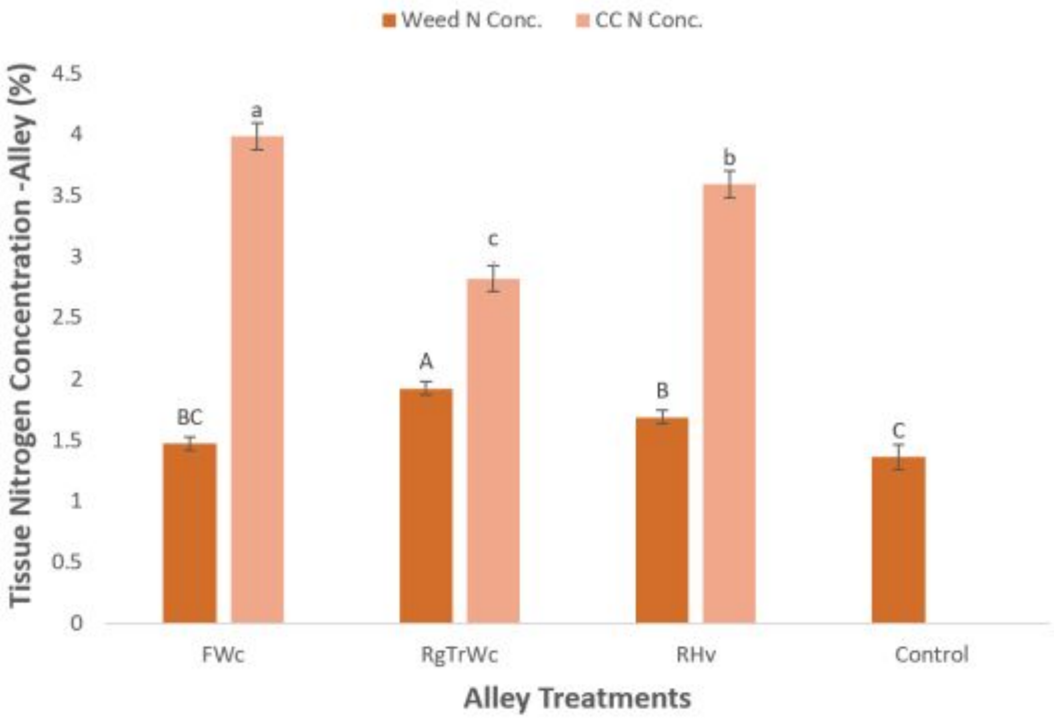
Crop	Unit	Apple[5]	Cherry
2020 seeded area[1] (ha)		17567	2096
Baseline Rotation Sequence		Apple>>herbicided alley	Cherry>>herbicided alley
Rotation Sequence with Cover Crop		Apple>>Alfalfa alley	Cherry>>Fescue or Ryegrass alley
Level of confidence		M	L
Maximum feasible adoption rate[2]	%	70	60
Soil carbon sequestration rate[3]	Mg/ha/yr	0.32	0.32
Estimated average cover crop above -ground dry matter per year of rotation cycle [2]	Mg/ha/y	7.4	4.11
Estimated average cover crop below-ground dry matter per year of rotation cycle [3]	Mg/ha/y	2.67	2.65
Estimated average total cover crop dry matter per year of rotation sequence	Mg/ha/y	6.34	4.26
Potential soil C gain rate per year of rotation sequence	Mg C/ha/y	2.029	1.363
Estimated total cover crop C contribution per year of rotation cycle per total seeded area in Canada	Mg C	24956	1714
Profit margins	$/y	$873,454	$59,980

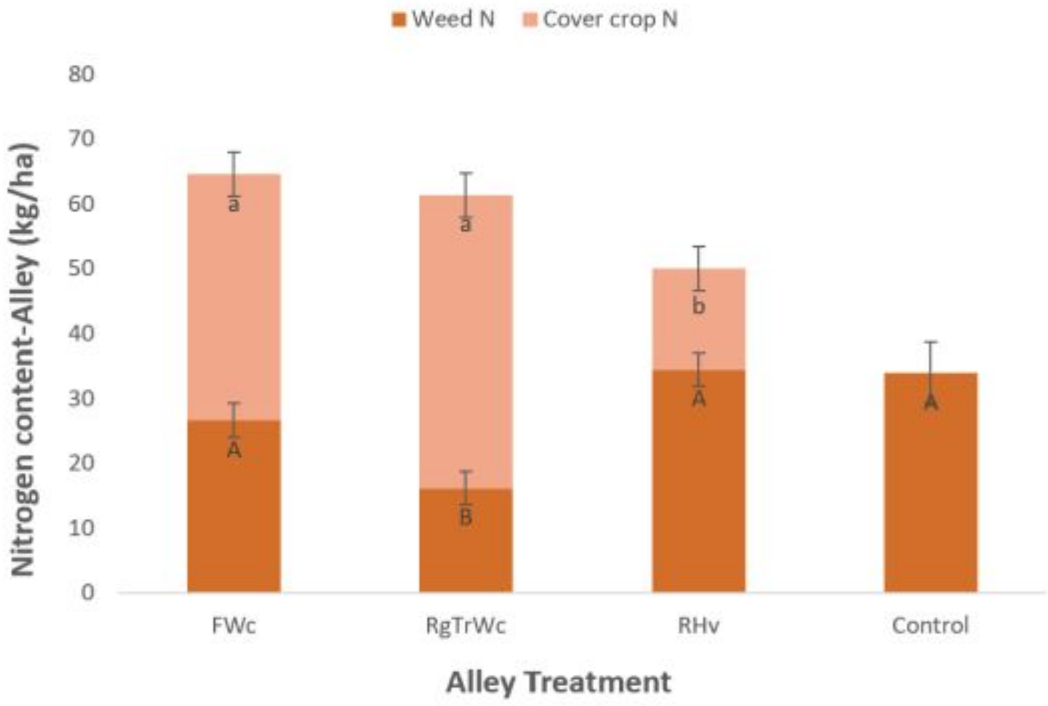
Assumptions: Soil organic C sequestration rate 0.32 Mg ha^{-1} yr^{-1} (Burton et al. 2021). Average C pricing for calculating profit margins was considered at $35/Mg based on Chahal et al. (2020); For horticultural crops only 2/3 of the land (alley ways were considered for cover crop calculations; The dry matter contribution of underseeded red clover (establishment year) was considered 1/2 of full red clover stand (2nd year). In vineyard and orchard 63% of the land is available for cover crops.

[1] Statistics Canada (2020)
[2] Clark (2008)
[3] Magdoff and Van Es (2000)
[4] Williams et al. (2013)
[5] Sharifi et al. (2016b)
[6] Messiga et al. (2015); Sharifi et al. (2016a)


Dry Biomass
Surface Coverage
Dry Biomass (kg/ha)
Surface Coverage (%)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
10
20
30
40
50
60
Balansa Clover
Berseem Clover
Persian Clover
Crimson Clover
Alsike Clover
Hairy Vetch+Cereal Rye
Field Pea+Cereal Rye
Crested Wheatgrass + Pubescent Wheatgrass
Indian Ricegrass+ Buckwehat
Blue grama
Western Wheatgrass
Tall Fescue+Red Fescue+Sheep Fescue
Perennial Ryegrass+Tillage Radish
Canada Blue Grass
Birdsfoot Trifoile +Western Wheatgrass
Alley Cover Crops- Covert Family Farm

Nitrogen Content and Concentration Alleyway





RgTrWc, Rygrass+Radish+White Clover; **FWc**, Fescue+White Clover; **RHv**, Fall rye+Hairy Vetch; **Control**, weeds

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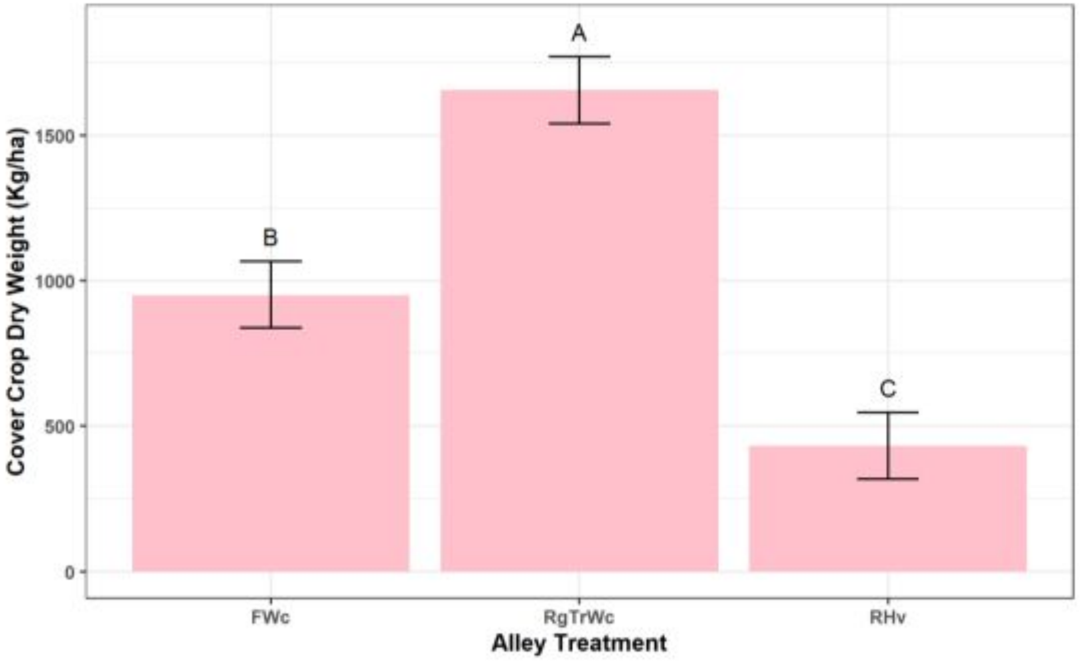
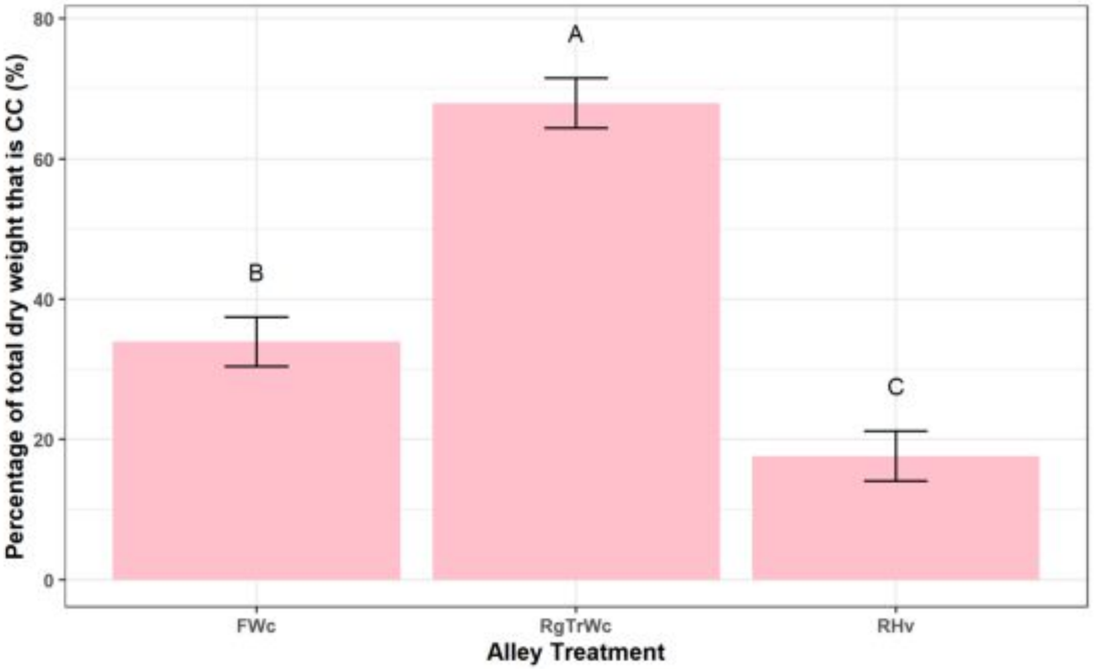
Sandy Loam soil texture

CC Biomass and Competition with Weeds Alleyway





RgTrWc, Rygrass+Radish+White Clover; **FWc**, Fescue+White Clover; **RHv**, Fall rye+Hairy Vetch

10

Sandy Loam soil texture

Oats/Pea/Vetch mixture
Swiss Sandwich System

(Sharifi et al., 2016)

Cover crop dry matter and total N uptake during 2012

Cover crop	Total DM ($Mg\ ha^{-1}$)[z]	Plant N uptake ($kg\ ha^{-1}$)[y]
Bare ground	0.84 *c*	32 *c*
RC-Oats	1.98 *a*	72 *b*
Peas-Oats-Vetch	2.23 *a*	88 *a*
Sweet clover-Oats	2.17 *a*	76 *b*
Triple mix	1.82 *ab*	73 *b*
Alfalfa	1.59 *b*	62 *b*

[Z] DM in bare ground was from the weed grew therein before 1st mowing.
[Y] Taking 64% of the alley area as available for growing cover crops.

Summary

- Fruit tree systems can fix significant amounts of carbon, but such potential has been largely unexplored.
- Baseline soil carbon stock in BC orchards need to be determined.
- Recycling and import of carbon sources are key practices for enhancing carbon sequestration and N cycling in orchards. Improving soil carbon stock contributes to soil health and larger active root zone.
- Cover crops are another important source of carbon for orchards. An efficient cover cropping system need to be developed for BC orchards.
- Soil organic carbon and input of carbon to the orchard soils need to be physically and chemically protected for maximum benefit. The potential of biochar and zeolite for enhancing carbon residence time in soil need to be explored.
- For coarse-textured soils precise irrigation and possibly soil amendments are needed to improve water holding capacity and lower NO_3^- under root zone.
- Climate change adaptation and mitigation management in orchards require long-term planning and investment.

Acknowledgments

- BCWGC, BCCA, SVC, and BCFGA
- SuRDC Field Service
- Summer students

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