Carbon sequestration and soil health outcomes in California integrated sheep-vineyard systems

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One foundational, yet understudied, design and management strategy to diversify U.S. farms is the integration of crops and livestock grazing within the same field and landscape[1,2]. While several decades of agricultural intensification have resulted in highly specialized and de-coupled farm-scale crop and livestock components[3], integrated crop-livestock (ICL) systems could provide a diverse array of grazing-based services for crop production[4,5]. Further, the decoupling of crop and livestock components contributes to poor nutrient cycling within and between agricultural operations, increasing the environmental footprint of both crop and livestock production throughout the world[5–7]. Current resource conservation incentives, regenerative agriculture movements, and the need to build soil health and utilize cropland to sequester additional soil organic carbon (SOC), have provided new opportunities to study and implement re-coupled crop and livestock production systems. The extremely diverse agricultural landscapes of California provide a unique opportunity for exploration and potential widespread re-integration, especially in vineyard systems.

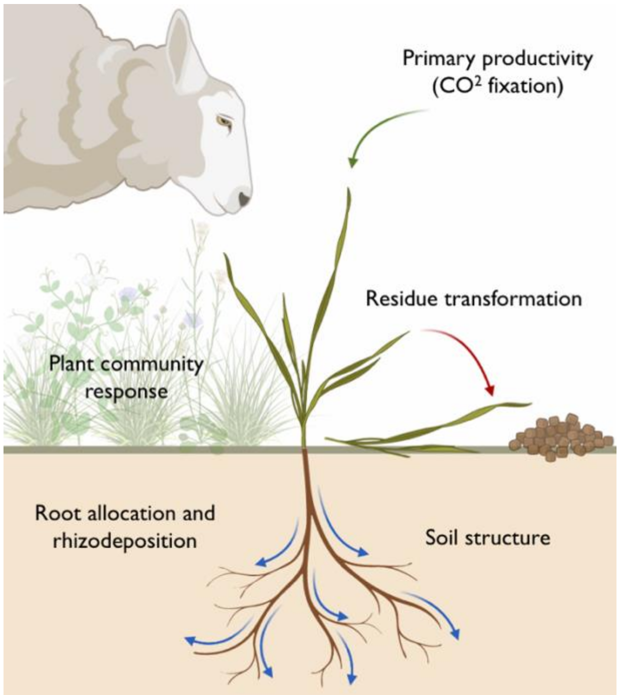

Figure 1: Shifts in carbon and nutrient cycling pathways with introduction of understory grazing in vineyards

Integrated sheep-vineyard management characteristics

Integrated sheep-vineyard (ISV) management, where small ruminant livestock graze on the vineyard understory, provides a feasible adoption opportunity to transition away from current petrochemically intensive understory management practices (such as mowing, herbicides, and tillage)[8]. ISV is therefore likely to reduce both the GHG and labor cost(s) of vineyard management[9]. Cropland grazing has also been shown to impact multiple ecosystem services related to soil functioning, including organic carbon sequestration and nutrient cycling[5,6,10,11] (***Figure 1***). While perceptions of ISV management in California are increasingly favorable among both adopters and non-adopters, vineyard grazing still remains a niche production system compared to the dominant technological regimes[3,12]. Most typically, sheep grazing is used to control and terminate vineyard winter understory plant community soon before vine bud break[12,13]. Sheep grazing may occur multiple times throughout vine dormancy and vegetative growing seasons, where it is strategically applied to achieve various production goals, such as vine leaf thinning and sucker removal[5,10,12,13]. The timing of grazing events varies with precipitation and understory plant growth rates.

Soil health outcomes of integrated sheep grazing in Northern California coastal vineyards

A research team from UC Davis conducted a soil survey of the interrow space in eight paired vineyards, across four locations throughout Northern California's winegrape growing region. The grazing strategies on all four of the integrated vineyards in this study are characterized as *high-density, short-duration rotational grazing* management[10] (***Figure 2***). This rotational grazing strategy incorporates small paddocks, that are grazed with high density and rotated frequently amongst smaller sections of the total vineyard, allowing for longer rest periods and a lower duration of grazing per unit of land area. Each location contained long-term management of one '*non-integrated*' vineyard (understory vegetation managed through mowing; CONV) and one adjacent '*integrated*' vineyard (understory vegetation managed through grazing for 10+ years; ISV) – with one location in Sonoma County, two in Lake County, and one in southern Mendocino County. Soil samples were taken at three depth zones (0–15 cm, 15–30 cm, and 30–45 cm) in the vine interrow and analyzed for soil health indicators.

Photo Credit: Paige Green, Fibershed (2017)

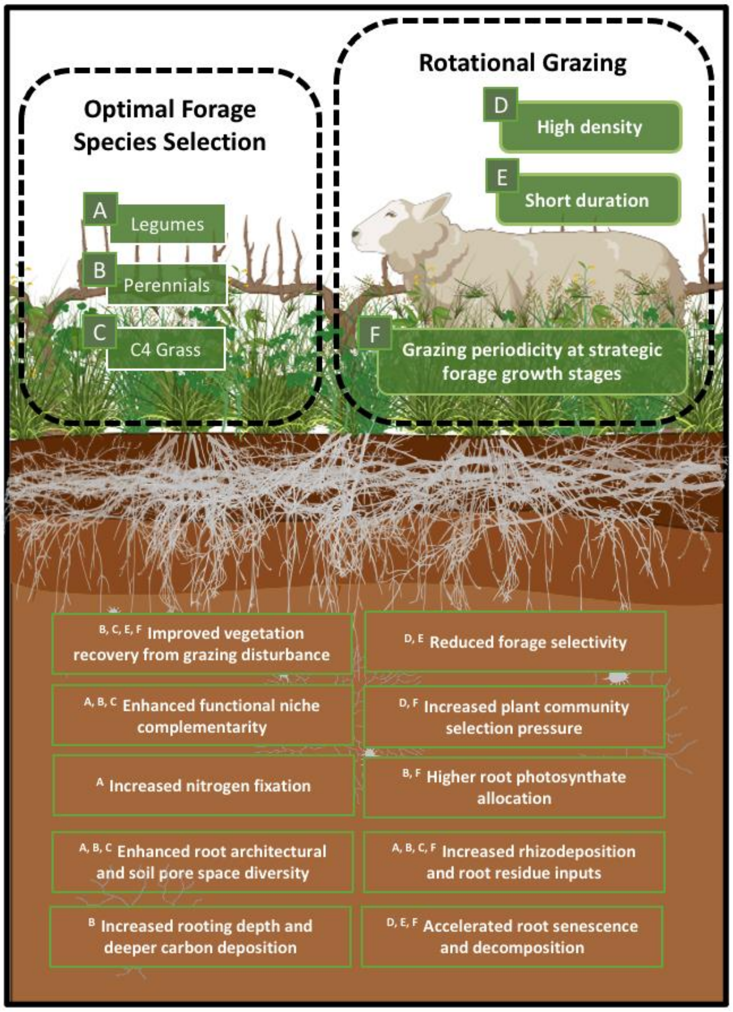

__Figure 2:__ Agroecosystem implications of sheep integration under best management. Ideal forage species mixtures are biodiverse and include legumes and high-residue grasses. Best grazing management utilized high density, short duration rotational grazing practices at strategic and site-specific forage growth periods. When managed properly and in tandem, these practices provide a suite of aboveground and belowground benefits. Letters on belowground text boxes represent influential practices (aboveground).

Long-term vineyard grazing increased soil carbon sequestration

Total soil organic carbon (SOC) was higher under ISV management at all three depth zones: *0–15 cm* (**+22%**) (26.1±1.2 vs. 21.4±0.9 g kg^{-1}), *15–30 cm* (**+39%**) (12.4±0.6 vs. 8.9±0.5 g kg^{-1}), and *30–45 cm* (**+34%**) (8.3±0.6 vs. 6.2±0.6 g kg^{-1}). Soil carbon storage was specifically higher under ISV management in the SOC fraction stored stably to the soil mineral matrix, as mineral-associated organic carbon (MAOC). The MAOC fraction is a measurement of the most persistent pool of SOC, generally with turnover periods of many decades, and therefore indicates a long-term carbon sequestration pathway. The MAOC fraction was only marginally higher under ISV in the *0–15 cm* surface soils (**+19%**) (15.8±0.6 vs. 13.3±0.6 g kg^{-1}), but the effect of vineyard grazing was most beneficial in the *15–30 cm* (**+28%**) (11.0±0.5 vs. 8.6±0.5 g kg^{-1}) and *30–45 cm* (**+37%**) (8.1±0.6 vs. 5.9±0.5 g kg^{-1}) subsoil depths.

Soil microbial communities were larger and more active under sheep-vineyard management

Microbial biomass was substantially higher under ISV management compared to CONV at all three depth zones: *0–15 cm* (**+85%**) (454±30 vs. 245±22 ug g^{-1}), *15–30 cm* (**+83%**) (174±15 vs. 94±9 ug g^{-1}), and *30–45 cm* (**+114%**) (150±12 vs. 70±7 ug g^{-1}) depth zones. Soil respiration, a measurement of biological activity in soils, also trended higher under ISV management at all three depth zones, but was especially higher within the *15–30 cm* depth (**+39%**). Within surface soils (*0–15 cm*), microbial nutrient cycling enzymes related to nitrogen (N) were also significantly more active, indicating faster N cycling rates under ISV management.

Soil N and P availability increased under sheep-vineyard management, especially in surface soils

The ISV treatment showed increases in surface soil (*0–15 cm*) bioavailable phosphorous (P) (**+72%**) (19.8±1.7 vs. 11.5±1.3 ug g^{-1}) and total nitrogen (TN) (**+31%**) (2.1±0.08 vs. 1.6±0.06 g kg^{-1}) compared to the CONV treatment, though both bioavailable P and TN were not altered in either subsoil depth zones (*15–30 cm* and *30–45 cm*). The bioavailable N fraction ($NH_4^+ + NO_3^-$) increased by **64%** under ISV management compared to CONV in surface soils (*0–15 cm*; 14.1±1.2 vs. 8.6±0.8 mg kg^{-1}), but was not significantly higher in *15–30 cm* and *30–45 cm* subsoil depths.

Soil structure was similar in both mowed and grazed vineyards

The physical characteristics of surface soils (0–15 cm) were not substantially affected by management, as represented by low treatment variability in bulk density (BD; 1.32±0.03 vs. 1.37±0.03 g cm^{-3}) and aggregate mean weight diameter (MWD; 1.47±0.13 vs. 1.44±0.12) values between ISV and CONV treatments, respectively.

Soil salinity is a potential trade-off of integrated sheep-vineyard management

The surface soils (0–15 cm) of ISV vineyards showed significant increases in salt content, as represented by **75%** higher electrical conductivity (EC) values compared to CONV soils (0.21±0.02 vs. 0.12±0.006 dS m^{-1}). While salt content was well below plant growth-limiting levels in all four ISV vineyards, soils with salinity concerns might not be well suited for vineyard grazing.

Key conclusions

This study provides supporting evidence that well-managed integrated sheep-vineyard (ISV) grazing can increase carbon sequestration within vineyard soils, especially the long-term stabilized mineral-associated SOC. Grazing-induced increases in soil microbial biomass and activity also indicate a higher potential for ISV to stimulate soil biological processes that improve soil health functioning, such as the cycling of soil N and P. Further, soil compaction was not observed to increase as a result of well managed vineyard grazing. This indicates that, where soil salinity is not a concern, strategically-applied ISV management holds significant potential to improve both environmental stewardship and resource management in California vineyards. However, these outcomes are strongly influenced by grazing intensity (herd density and grazing duration) and soil outcomes are therefore variable. Strategic applications of ISV management, by knowledgeable shepherd practitioners, is likely necessary to optimize soil health benefits.

Collaborators

Funding

Literature cited

1. Russelle MP, Entz MH, Franzluebbers AJ. Reconsidering integrated crop-livestock systems in North America. In: *Agronomy Journal*. Vol 99. ; 2007:325-334. doi:10.2134/agronj2006.0139
2. Entz MH, Bellotti WD, Powell JM, et al. Evolution of integrated crop-livestock production systems. *Grassl A Glob Resour*. 2005:137-148. doi:10.3920/978-90-8686-551-2
3. Garrett RD, Ryschawy J, Bell LW, et al. Drivers of decoupling and recoupling of crop and livestock systems at farm and territorial scales. *Ecol Soc*. 2020. doi:10.5751/ES-11412-250124
4. Sanderson MA, Archer D, Hendrickson J, et al. Diversification and ecosystem services for conservation agriculture: Outcomes from pastures and integrated crop-livestock systems. *Renew Agric Food Syst*. 2013;28(2):129-144. doi:10.1017/S1742170512000312
5. Brewer KM, Gaudin ACM. Potential of crop-livestock integration to enhance carbon sequestration and agroecosystem functioning in semi-arid croplands. *Soil Biol Biochem*. 2020. doi:10.1016/j.soilbio.2020.107936
6. Lemaire G, Franzluebbers A, Carvalho PC de F, Dedieu B. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agric Ecosyst Environ*. 2014;190:4-8. doi:10.1016/j.agee.2013.08.009
7. Garrett RD, Niles MT, Gil JDB, et al. Social and ecological analysis of commercial integrated crop livestock systems: Current knowledge and remaining uncertainty. *Agric Syst*. 2017;155:136-146. doi:10.1016/j.agsy.2017.05.003
8. Schoof N, Kirmer A, Hörl J, et al. Sheep in the vineyard: First insights into a new integrated crop–livestock system in central europe. *Sustain*. 2021. doi:10.3390/su132212340
9. Lazcano C, Gonzalez-Maldonado N, Yao EH, et al. 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. *Agric Ecosyst Environ*. 2022;327:107825. doi:https://doi.org/10.1016/j.agee.2021.107825
10. de Faccio Carvalho PC, Anghinoni I, de Moraes A, et al. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. *Nutr Cycl Agroecosystems*. 2010;88(2):259-273. doi:10.1007/s10705-010-9360-x
11. Jarvis SC. Soil-plant-animal interactions and impact on nitrogen and phosphorus cycling and recycling in grazed pastures. In: *Grassland Ecophysiology and Grazing Ecology*. ; 2009. doi:10.1079/9780851994529.0317
12. Ryschawy J, Tiffany S, Gaudin A, Niles MT, Garrett RD. Moving niche agroecological initiatives to the mainstream: A case-study of sheep-vineyard integration in California. *Land use policy*. 2021. doi:10.1016/j.landusepol.2021.105680
13. Niles MT, Garrett RD, Walsh D. Ecological and economic benefits of integrating sheep into viticulture production. *Agron Sustain Dev*. 2018;38(1). doi:10.1007/s13593-017-0478-y

Kaos Sheep Outfit grazing a vineyard in Lake County, California, USA.
Photo Credit: Paige Green, Fibershed (2017)