The Influence of Land Conversion on Carbon Mineralization and CO_2 Emissions from Vineyards and Adjacent Oak Woodlands in the Napa Valley

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Problem:

Oak woodlands and oak woodland grasslands in the Napa Valley historically have been converted to orchards and then to vineyards. Vineyard systems that were converted roughly 30 years ago have lost an estimated 33 Mg carbon (C) ha^{-1} from the upper 20 cm soil in comparison to adjacent oak woodlands (Carlisle and Smart, unpublished data). Substantial areas of coastal California have undergone conversion, and the consequences of such disturbance on C flows and C cycling are unknown.

Objectives:

• Examine the magnitude of seasonal CO_2 fluxes from both an oak woodland-grassland and vineyards in close proximity.

• Determine physical cause of the difference in soil CO_2 efflux between the sites

Materials and Methods:

• All sites were located on similar soils, a Bale (variant) gravelly loam (fine-loamy, mixed, superactive, thermic Cumulic Ultic Haploxeroll).

• Oak woodland (Figure 1) and adjacent vineyard (Figure 2) were measured for soil CO_2 efflux using a Licor-6400 with soil chamber attachment. Measurements were made approximately every two weeks for 15 months between the hours of 12 and 2 pm.

• Soil CO_2 profile arrays consisting of $^1/_8$ inch stainless steel tubes capped with septa were installed at 15, 25, 45, 65, 85, and 105 cm depth and sampled for CO_2 concentrations and $d^{13}C$ at depth.

• Soil temperature and gravimetric moisture were measured concurrently with the efflux. Both efflux and profile measurements were made under the oak or vineyard canopy.

Figure 1: One of our oak woodland sites, Oakville, Napa Valley California

Figure 2: One of the vineyard sites in Oakville, Napa Valley, California

Results & Discussion:

• Vineyard soils have less carbon, greater bulk densities throughout the soil profile, and lower CO_2 diffusion coefficients than do the oak woodland soils (Table 1). These differences are likely a result of the conversion of oak woodlands to agricultural systems.

CO_2 Efflux

• Oak sites have much greater rates of CO_2 efflux than the vineyard soils. The oak sites also show a greater response to rainfall and a strong increase in CO_2 following bud break, when the rate of fine root emergence is higher (Figure 3a).

• Estimated annual loss of carbon through soil respiration is 15.761 ± 1.44 Mg C ha^{-1} and 7.022 ± 0.58 Mg C ha^{-1} for the oak woodlands and vineyards respectively.

Soil Temperature and Soil Moisture

• Soil moisture ($P < 0.0043$; Figure 3b), rather than soil temperature ($P = 0.0580$; Figure 3c), is the most important factor in determining soil respiration in the oak sites (adj. $R^2 = 0.3052$;) However, neither soil moisture ($P = 0.2756$; Figure 3b) nor temperature ($P = 0.4149$; Figure 3c) explained much of the variation in vineyard sites (adj. $R^2 = 0.0028$).

CO_2 in the Soil Profile

• The greater CO_2 concentration found at the 15 and 25 cm depth (Figure 5) during the wet season (winter and spring) is most likely a result of greater microbial and root respiration in the oak soils. Greater CO_2 concentrations below 15 cm in the vineyard soils is possibly a function of decreased gas movement (Table 1) and elevated root respiration at these depths. Lower concentrations throughout the profile for both soils in the dry (summer and fall) season is related to lower microbial activity and increased air-filled porosity allowing for faster movement through the profile

• There was an obvious seasonal shift in $\delta^{13}C$ of CO_2 to a more positive value in both the oak woodland and vineyard soils beneath approximately 15 cm (Figure 5), and the shift was much larger in the oak woodland soils. The shift to a more enriched $\delta^{13}C$ value corresponded to a decrease in soil moisture content (Figure 3b), increased soil temperature (Figure 3c) and a decline in soil [CO_2] (Figure 4) Oak soil CO_2 is generally more enriched in ^{13}C than the vineyard soil (Figure 5). This observation suggests that there is a difference in soil CO_2 diffusivity between these soils, and measured CO_2 diffusion coefficients support this hypothesis (Table 1). At all depths measured, vineyard soils have lower diffusion coefficients than oak soils.

Table 1: Shown are the means and standard errors of the means (n = 6) for total soil C and N, KCl extractable NH_4^+-N and NO_3^--N, texture (% sand, silt, and clay), bulk density (?$_b$), and measured diffusion coefficients (D_g)

		Vineyard	Oak
Total -C	%	2.48 ± 0.03	4.63 ± 0.13
Total -N	%	0.21 ± 0.01	0.35 ± 0.01
NH_4^+-N	ppm	3.02 ± 0.25	12.23 ± 1.36
NO_3^--N	ppm	2.75 ± 0.26	2.20 ± 0.14
Sand	%	49.33 ± 1.03	49.67 ± 1.37
Silt	%	33.67 ± 1.23	37.67 ± 1.21
Clay	%	17.00 ± 0.01	12.67 ± 0.52
?$_b$ 0-6 cm	g/cm^3	1.25 ± 0.06	1.02 ± 0.05
?$_b$ 6-12 cm	g/cm^3	1.33 ± 0.10	1.16 ± 0.08
?$_b$ 40-46 cm	g/cm^3	1.45 ± 0.05	1.20 ± 0.02
D_g 0-6 cm	cm^2/s	0.0033 ± 0.0008	0.0057 ± 0.0031
D_g 6-12 cm	cm^2/s	0.0018 ± 0.0011	0.0036 ± 0.0016
D_g 40-46 cm	cm^2/s	0.0029 ± 0.0009	0.0091 ± 0.0011

Figure 3: Bi-monthly measurements of (a) soil CO2 efflux, (b) soil gravimetric water content, and (c) soil temperature are shown. Points represent means (n = 3), and error bars indicate standard error. Soil moisture and temperature measurements were taken to 20 cm depth.

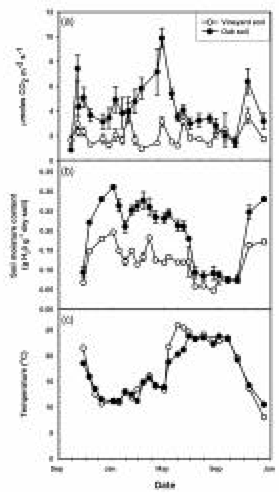


Figure 4: Seasonal means and standard errors of the means of soil profile CO2 concentrations in oak woodland and vineyard soils. During the winter and spring some sites were so waterlogged as to prevent sample gas extraction. As a result winter and spring points are composed of n = 3-6 data points while summer and fall points are composed of n = 12 data points.

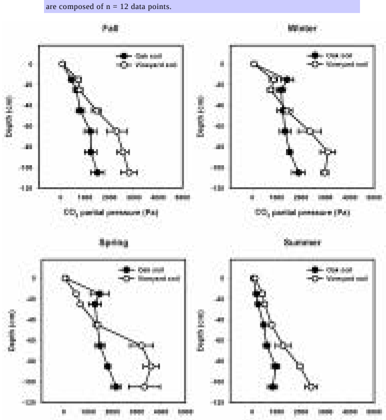
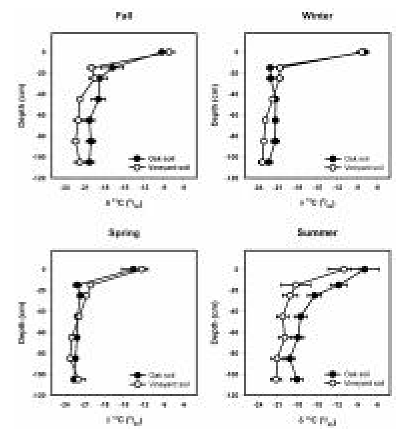


Figure 5: Seasonal means and standard errors of the means of soil profile CO_2 $d^{13}C$ values in oak woodland and vineyard soils. During the winter and spring some sites were so waterlogged as to prevent sample gas extraction. As a result, winter and spring points are composed of n = 3-6 data points while summer and fall points are composed of n = 12 data points.



• Other factors such as differential diffusion rates of $^{13}CO_2$ and $^{12}CO_2$, microbial activity, age of the soil organic matter, and different relative contributions of root respiration to the total CO_2 production may explain the $\delta^{13}C$ values in the profile below 25 cm.

• The highly enriched $d^{13}C$ values in the oak woodland soils during the summer may have been a result of easier exchange of atmospheric CO_2 ($d^{13}C$ of –8‰) into the soil profile as diffusion constants increased with lower soil moisture, at least for the 15 cm depth. The more positive CO_2 $d^{13}C$ values of the remainder of the oak woodland soil profile relative to the vineyard soil profile may have been produced by deeper (> 1 m), older and more highly degraded SOC.

Conclusions:

• Vineyard soils have lost roughly 33 Mg C ha^{-1} over the last 30-32 years relative to the oak woodland soils.

• Conversion of undisturbed oak woodland systems to perennial agricultural systems such as vineyards changes physical soil properties, including bulk density and gas diffusion coefficients, and decreases the total carbon content of the soil.

Future Research:

• Laboratory incubations of soils from different depths will be initiated to study $d^{13}C$ fractionation with soil depth and variation in carbon source.

• Root versus microbial contribution to soil respiration will be measured.

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