Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands

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Acronyms & Abbreviations

ac	acre
ASAE	American Society of Agricultural Engineers
C	carbon
CARB	California Air Resources Board
CDFA	California Department of Food and Agriculture
CH_4	methane
cm	centimeters
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DOC	dissolved organic carbon
DNDC	DeNitrification-DeComposition
E_h	redox potential
g	gram
GHG	greenhouse gases
H_2S	hydrogen sulfide
lb	pound
mm	millimeter
MT	metric ton
N	nitrogen
N_2O	nitrous oxide
NASS	National Agricultural Statistics Service
NH_3	ammonia
NH_4^+	ammonium
NO	nitric oxide
pH	potential for hydrogen
SOC	soil organic carbon
SSURGO	Soil Survey Geographic Database
UCD	University of California, Davis
USDA	US Department of Agriculture

Background

Emissions of the greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), from agricultural soils are results of biological activities and hence are affected by soil and environmental factors. This document describes the methodology that was used for estimating GHG emissions from agricultural soils that receive compost application as a means to increase soil carbon sequestration and reduce overall GHG emissions from soils. The process-based model, DeNitrification-DeComposition (DNDC), was chosen as the quantitative tool because 1) the model has been tested and validated extensively against major cropping systems in California, and 2) we have established a California-specific activity database for the DNDC model that represents California's agricultural land uses, soil properties, weather conditions, and crop management practices.

Methodology

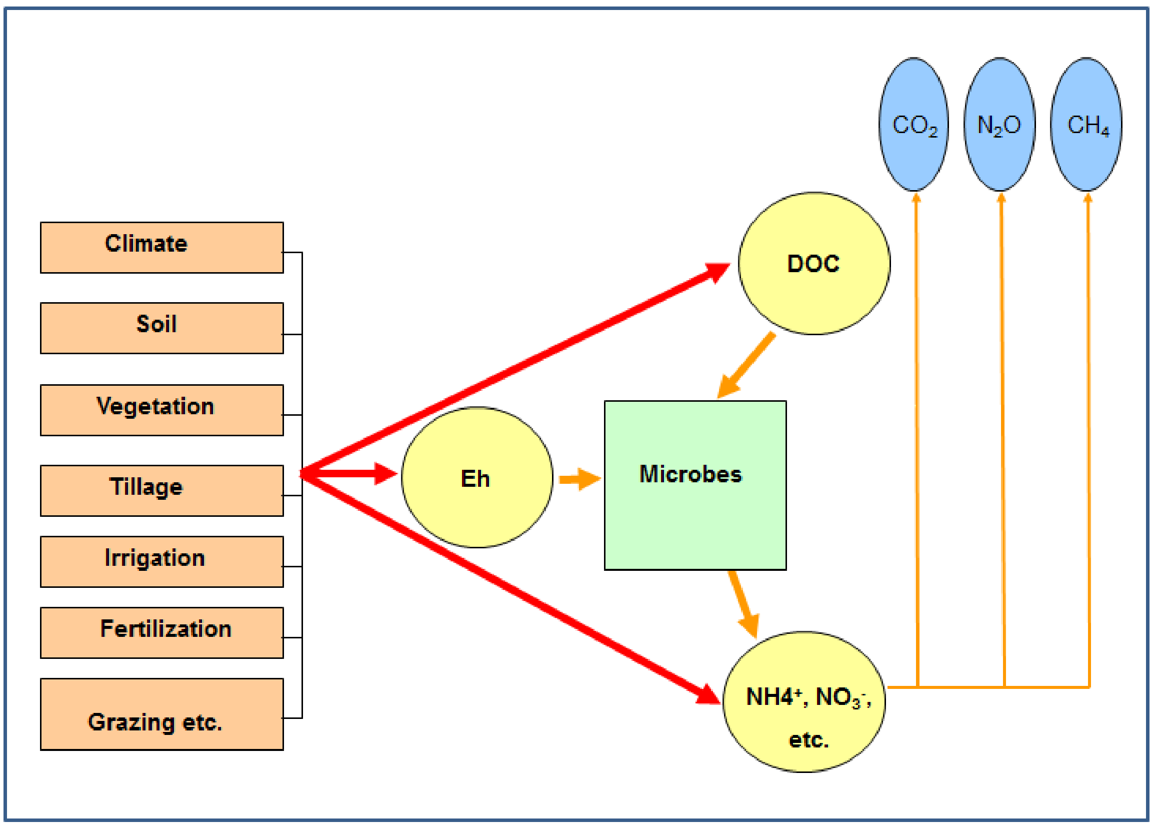
DNDC model

The Denitrification-Decomposition model (Li et al., 1992; Li, 2000) is a process-based computer simulation model of carbon (C) and nitrogen (N) biogeochemistry and was developed for quantifying carbon sequestration and emissions of greenhouse gases in agroecosystems. The core of DNDC modeling consists of microbe-mediated biochemical processes commonly occurring in terrestrial soils. The processes simulated include decomposition, nitrification, denitrification, fermentation, and methanogenesis. A full description of the DNDC scientific basis and processes, including all equations involved, is available at http://www.dndc.sr.unh.edu/.

DNDC simulates rates of the processes by tracking activities of different groups of microbes which are activated under various environmental conditions in response to temperature, moisture, pH, redox potential (E_h) and substrate concentration gradient in soil. Nitrification-induced N_2O production is modeled as first order of soil ammonium (NH_4^+) concentration under aerobic conditions. Denitrification induced N_2O production is initiated once soil is saturated, which is assumed to lead to anaerobic conditions. Soil E_h is calculated with the Nernst equation at a daily time step following soil saturation and used to determine anaerobic microbial group activities under the given soil conditions. The anaerobic microbial group activity is then modeled using standard Michaelis-Menten-type kinetics.

The hypotheses backing the DNDC simulations of soil GHG emissions include: a) CO_2, N_2O and CH_4 are products of oxidation-reduction reactions through electron exchange between electron donors and acceptors that is mediated by microbes; b) the occurrence of the electron exchange is determined by the soil E_h that is described by the Nernst Equation, a thermodynamic equation calculating E_h based on the concentrations of paired oxidative and reductive forms of dominant oxidants in the soil; c) when the suitable E_h is established, the functional groups of bacteria will grow to their full capacity within a short timeframe (hours or days) due to rapid regeneration; and d) when the microbial capacity is established, the reaction rate will be primarily controlled by the concentrations of the relevant substrates based on the Michaelis-Menten Equation. DNDC currently tracks microbial activities primarily based on three drivers, i.e., E_h, dissolved organic carbon (DOC) as electron donor and oxidants as electron acceptors. Nitrification-induced N_2O production is integrated into DNDC with ammonium (NH_4^+) and ammonia (NH_3) levels under aerobic conditions as a major driver. Figure 1 provides a functional overview of DNDC and how climate, soil, vegetation and management practices influence E_h, DOC, substrate concentrations and GHG emissions.

Figure 1. DNDC Functional Overview.



In DNDC, soil organic carbon (SOC) resides in four major pools: plant residue (i.e., litter), microbial biomass, humads (i.e., active humus), and passive humus. Each pool consists of two or three sub-pools with specific decomposition rates. Daily decomposition rate for each sub-pool is regulated by the pool size, the specific decomposition rate, soil clay content, N availability, soil temperature, and soil moisture. When SOC in a pool decomposes, the decomposed carbon is partially lost as CO_2 with the rest allocated into other SOC pools. DOC is produced as an intermediate during decomposition, and can be immediately consumed by the soil microbes. During the processes of SOC decomposition, the decomposed organic nitrogen partially transfers to the next organic matter pool and is partially mineralized to NH_4^+. The free NH_4^+ concentration is in equilibrium with both the clay-adsorbed NH_4^+ and the dissolved NH_3. Volatilization of NH_3 to the atmosphere is controlled by NH_3 concentration in the soil's liquid phase and subject to soil environmental factors (e.g., temperature, moisture, and pH). When rainfall or irrigation occurs, NO_3^- leaches into deeper layers with the soil drainage flow. A simple kinetic scheme "anaerobic balloon" in the model predicts the soil aeration status by calculating oxygen or other oxidants content in the soil profile. Based on the predicted redox potential, the soil, discretized into 2-cm layers, is divided into aerobic and anaerobic pockets where nitrification and denitrification occur, respectively. When the anaerobic balloon swells, more substrates (e.g., DOC, NH_4^+, and N oxides) are allocated to the anaerobic microsites to enhance denitrification. When the anaerobic balloon shrinks, nitrification will be enhanced due to the reallocation of the substrates into the aerobic microsites. The nitric oxide (NO) and N_2O gases produced in either nitrification or denitrification are subject to further transformation during their diffusion through the soil matrix. Long-term submergence will activate fermentation, which produces hydrogen sulfide (H_2S) and methane (CH_4) driven by decreasing of the soil E_h.

GHG Emission Calculations

The GHG emission calculations were performed by linking DNDC with a California-specific database containing spatial and temporal information on weather, crop, soil, and farming management practices in California. For each crop and compost implementation, DNDC was run for three consecutive years, initializing the model and allowing the distribution of carbon and nitrogen speciation in soil to match closely to field conditions. The results for the third year were used as the annual emission estimate. The overall impact of the compost application for a given crop was calculated as the sum of the changes in carbon dioxide, nitrous oxide, and methane between the business as usual scenario (baseline case with no compost application) and that with the compost implementation.

The CO_2 emissions were calculated based on SOC changes, consistent with the USDA's methodology for COMET-Planner (Swan et al., 2016). Total SOC excluding crop residue carbon in the top 50-cm soil profile was considered in CO_2 accounting. Crop residue carbon was excluded from SOC (i.e., from soil sequestered carbon) because of its rapid breakdown to CO_2 and subsequent release to the atmosphere. The N_2O emission estimates represent direct emissions from fertilizer use, compost application and crop residues. The CH_4 emissions estimates are emissions resulting from decomposition of SOC or crop residues. Positive values indicate reductions in greenhouse gas emissions and negative values indicate increases in greenhouse gas emissions.

Activities and Data Sources

The California-specific database contained information on (1) daily meteorological parameters, (2) land area of different crop types, (3) soil properties, and (4) farming management practices. These data were collected and organized per county per crop. For this specific application, the model was run with 2012 activity data for three years under 1998-2000 weather conditions and the 2000 results were used as emissions estimates. The year 2000 was chosen to be consistent with COMET-Farm for historic GHG emissions assessment (USDA, 2016a) and to avoid the extraordinary drought conditions encountered in California post 2012.

Meteorological data. Daily meteorological data were derived from weather data produced by the DAYMET model (Thornton et al., 2015). DAYMET climate data are available for the United States at 1-km^2 resolution, and the data from the 1-km^2 cell that was closest to the area-weighted geographical center of croplands in each county were used to drive the DNDC. The four weather parameters collected were minimum and maximum air temperatures, precipitation, and solar radiation.

Crop areas. County level crop area data for 2012 were obtained from the U.S. Department of Agriculture's (USDA's) National Agricultural Statistics Service (NASS), Quick Stats (USDA, 2016b). The crops reported in NASS QuickStats were reclassified into 54 cropping systems that are represented in the DNDC model. These cropping systems were further grouped into three broader crop categories (annual crops, perennials/trees, and grassland) that match the categorization of CDFA compost practice implementations for further aggregation of GHG reductions (Table 1).

Table 1. Areas of cropping systems included in the DNDC model and the corresponding crop categories for GHG reduction aggregation.

DNDC cropping system	Compost application crop category	Area, acres
Alfalfa	Perennials	942678
Almonds	Trees	811567
Apples	Trees	13956
Apricots	Trees	9185
Artichokes	Annual Crops	6682
Asparagus	Annual Crops	10173
Avocados	Trees	47718
Barley	Annual Crops	73388
Beans, dry	Annual Crops	56286
Beans, green	Annual Crops	18624
Beets	Annual Crops	29022
Berries	Annual Crops	40244

DNDC cropping system	Compost application crop category	Area, acres
Broccoli	Annual Crops	100236
Cabbage	Annual Crops	12387
Carrots	Annual Crops	48774
Cauliflower	Annual Crops	32825
Celery	Annual Crops	7633
Cherries	Trees	32381
Citrus, other	Trees	208403
Corn, grain	Annual Crops	208485
Corn, silage	Annual Crops	487593
Cotton	Annual Crops	367791
Dates	Trees	4401
Figs	Trees	5229
Fruit, other	Trees	35148
Garlic	Annual Crops	20191
Grapes	Trees	769945
Lemons	Trees	41598
Lettuce	Annual Crops	227396
Melons	Annual Crops	65977
Non legume hay	Annual Crops	799884
Nuts, other	Trees	268472
Oats	Annual Crops	20206
Olives	Trees	35759
Onions	Annual Crops	39957
Pasture	Grassland	412833
Peach	Trees	60679
Pears	Trees	10907
Peppers	Annual Crops	25546
Pistachios	Trees	180878
Plums	Trees	21249
Potatoes	Annual Crops	40122
Prunes	Trees	52609
Rice[1]	Excluded	555690
Safflowers	Annual Crops	48400
Sorghum	Annual Crops	54884
Spinach	Annual Crops	20977
Squash	Annual Crops	13260
Sunflowers	Annual Crops	49762
Sweet potatoes	Annual Crops	15293

DNDC cropping system	Compost application crop category	Area, acres
Tomatoes	Annual Crops	288119
Vegetables, other	Annual Crops	61462
Wheat, spring	Annual Crops	175748
Wheat, winter	Annual Crops	310490

[1] Rice is an available DNDC cropping system but is not included in the quantification of compost application.

Soil data. Soil data were collected from USDA's Soil Survey Geographic Database (SSURGO) database (USDA, 2016c). Key soil data, including soil organic carbon content, clay content, pH and bulk density, were compiled. The SSURGO map units were overlaid with the regions of agricultural land use developed by the Land Use Surveys of the California Department of Water Resources (CDWR, 2014) and the area-weighted means of the four soil properties were calculated for each county and used as "representative" soil values for DNDC simulation (Table 2).

Table 2. Major soil property values used in the DNDC modeling.

County	SOC weight fraction	Clay weight fraction	pH	Bulk density, g/cm3
Alameda	0.010	0.284	6.453	1.378
Alpine	0.019	0.139	6.468	1.340
Amador	0.010	0.148	6.116	1.529
Butte	0.016	0.372	5.278	1.354
Calaveras	0.005	0.130	6.375	1.475
Colusa	0.011	0.302	6.597	1.444
Contra Costa	0.008	0.331	7.056	1.464
Del Norte	0.069	0.240	5.116	1.082
El Dorado	0.012	0.165	6.055	1.375
Fresno	0.006	0.238	7.146	1.478
Glenn	0.009	0.305	6.275	1.450
Humboldt	0.023	0.226	6.134	1.461
Imperial	0.003	0.317	8.086	1.495
Inyo	0.009	0.119	6.762	1.471
Kern	0.003	0.192	7.335	1.515
Kings	0.006	0.184	7.571	1.520
Lake	0.011	0.224	6.425	1.493
Lassen	0.013	0.238	6.998	1.374
Los Angeles	0.006	0.142	6.536	1.503
Madera	0.005	0.125	6.610	1.547
Marin	0.015	0.196	6.030	1.489

County	SOC weight fraction	Clay weight fraction	pH	Bulk density, g/cm3
Mariposa	0.015	0.191	6.004	1.448
Mendocino	0.017	0.239	6.202	1.430
Merced	0.006	0.199	6.822	1.516
Modoc	0.012	0.225	6.893	1.398
Mono	0.020	0.130	6.711	1.320
Monterey	0.013	0.214	6.611	1.433
Napa	0.012	0.239	6.055	1.410
Nevada	0.021	0.174	6.097	1.247
Orange	0.010	0.219	6.903	1.504
Placer	0.007	0.151	6.045	1.527
Plumas	0.013	0.150	6.455	1.517
Riverside	0.005	0.171	7.094	1.537
Sacramento	0.006	0.223	6.181	1.533
San Benito	0.015	0.289	7.073	1.477
San Bernardino	0.007	0.107	6.743	1.450
San Diego	0.006	0.144	6.194	1.538
San Francisco	0.017	0.255	6.750	1.400
San Joaquin	0.010	0.236	6.742	1.511
San Luis Obispo	0.012	0.260	6.810	1.477
San Mateo	0.013	0.231	5.906	1.448
Santa Barbara	0.012	0.170	6.244	1.513
Santa Clara	0.013	0.338	6.839	1.408
Santa Cruz	0.013	0.175	6.480	1.498
Shasta	0.014	0.216	6.112	1.411
Sierra	0.014	0.188	6.454	1.403
Siskiyou	0.010	0.178	6.524	1.392
Solano	0.009	0.353	6.529	1.464
Sonoma	0.012	0.235	5.745	1.442
Stanislaus	0.006	0.186	6.702	1.528
Sutter	0.009	0.329	6.755	1.443
Tehama	0.009	0.203	6.327	1.484
Trinity	0.011	0.211	6.417	1.420
Tulare	0.007	0.205	7.209	1.497
Tuolumne	0.017	0.194	5.861	1.260
Ventura	0.012	0.218	6.903	1.472
Yolo	0.010	0.316	6.707	1.455
Yuba	0.008	0.219	6.305	1.477

Farming management data. Farming management data, including planting and harvest dates, tillage, fertilization, irrigation, and residue management, were developed for the crops largely from open literature, surveys, as well as personal communications with researchers, growers, and University of California Cooperative Extension staff. There was no discernable trend in N fertilizer application rates in the past 25 years so static N application rates for 2000 to 2015 were used. Nitrogen fertilizer use (rates, types, and schedule) were based on the "Cost and Return Studies" developed by the University of California, Davis (UCD, 2000-2015) and literature reviews (for example, Rosenstock et al., 2013). Irrigation methods for the crops were assumed to change over time per the CDWR's Statewide Irrigation Methods Surveys (CDWR, 2015). The four irrigation methods included are surface gravity irrigation (flooding), sprinkler irrigation, surface drip, and subsurface drip. Fractions of irrigation methods for 2012 for each crop were obtained using linear extrapolation from 2000 and 2010 survey results. The baseline irrigation method and irrigation water depth for each crop were first determined from the "Cost and Return Studies" (UCD, 2000-2015). The baseline irrigation depth was then varied using the factor of 1.58, 1.27, 1.06, and 1.0 for flooding, sprinkler irrigation, surface drip, and subsurface drip, respectively, consistent with the reported water use efficiencies of the four irrigation methods of 60%, 75%, 90%, and 95% for flooding, sprinkler irrigation, surface drip, and subsurface drip, respectively (Brouwer et al. 1989). The final irrigation depth was further adjusted for each county based on the ratio of the county's annual mean air temperature to the state-mean air temperature so that more irrigation water would be applied for counties with a higher air temperature. Tables 3 and 4 provides data on major management activities for the cropping systems simulated by DNDC.

Table 3. Major crop irrigation management inputs for the DNDC model.

DNDC system	Flooding, fraction	Sprinkler, fraction	Surface drip, fraction	Sub-surface drip, fraction	Flooding, mm water	Sprinkler, mm water	Surface drip, mm water	Sub-surface drip, mm water
Alfalfa	0.764	0.179	0.029	0.029	1090	886	750	681
Almonds	0.120	0.146	0.367	0.367	1340	1088	921	837
Apples	0.309	0.263	0.214	0.214	1150	935	791	719
Apricots	0.309	0.263	0.214	0.214	1118	909	769	699
Artichokes	0.217	0.411	0.186	0.186	1150	935	791	719
Asparagus	0.217	0.411	0.186	0.186	779	633	535	487
Avocados	0.046	0.154	0.400	0.400	959	779	659	599
Barley	0.771	0.136	0.046	0.046	469	381	323	294
Beans, dry	0.686	0.162	0.076	0.076	831	675	571	519
Beans, green	0.686	0.162	0.076	0.076	779	633	535	487
Beets	0.823	0.037	0.070	0.070	1867	1517	1284	1167
Berries	0.217	0.411	0.186	0.186	895	727	615	559
Broccoli	0.217	0.411	0.186	0.186	1566	1272	1076	979
Cabbage	0.217	0.411	0.186	0.186	1726	1402	1186	1078
Carrots	0.217	0.411	0.186	0.186	1090	886	750	681
Cauliflower	0.217	0.411	0.186	0.186	1789	1454	1230	1118
Celery	0.217	0.411	0.186	0.186	766	622	526	478
Cherries	0.309	0.263	0.214	0.214	959	779	659	599
Citrus, other	0.046	0.154	0.400	0.400	959	779	659	599
Corn, grain	0.765	0.010	0.112	0.112	1142	928	785	714
Corn, silage	1.000	0.000	0.000	0.000	1246	1013	857	779
Cotton	0.683	0.078	0.119	0.119	1558	1266	1071	974
Dates	0.040	0.157	0.401	0.401	2337	1898	1607	1461
Figs	0.046	0.154	0.400	0.400	907	736	623	566
Fruit, other	0.309	0.263	0.214	0.214	1585	1287	1089	991
Garlic	0.136	0.353	0.256	0.256	829	673	570	518
Grapes	0.202	0.009	0.395	0.395	221	180	152	138

DNDC system	Flooding, fraction	Sprinkler, fraction	Surface drip, fraction	Sub-surface drip, fraction	Flooding, mm water	Sprinkler, mm water	Surface drip, mm water	Sub-surface drip, mm water
Lemons	0.046	0.154	0.400	0.400	1246	1013	857	779
Lettuce	0.217	0.411	0.186	0.186	479	389	330	300
Melons	0.516	0.077	0.204	0.204	1298	1054	893	811
Non legume hay	0.658	0.155	0.093	0.093	727	591	500	454
Nuts, other	0.309	0.263	0.214	0.214	1071	871	737	670
Oats	0.771	0.136	0.046	0.046	0	0	0	0
Olives	0.046	0.154	0.400	0.400	1358	1103	934	849
Onions	0.136	0.353	0.256	0.256	1146	932	788	717
Pasture	0.671	0.268	0.031	0.031	1090	886	750	681
Peach	0.309	0.263	0.214	0.214	1585	1287	1089	991
Pears	0.309	0.263	0.214	0.214	959	779	659	599
Peppers	0.217	0.411	0.186	0.186	907	736	623	566
Pistachios	0.120	0.146	0.367	0.367	1774	1442	1220	1109
Plums	0.309	0.263	0.214	0.214	1142	929	785	714
Potatoes	0.022	0.789	0.095	0.095	735	597	505	459
Prunes	0.309	0.263	0.214	0.214	957	777	657	597
Safflowers	0.527	0.473	0.000	0.000	156	127	107	97
Sorghum	0.658	0.155	0.093	0.093	779	633	535	487
Spinach	0.217	0.411	0.186	0.186	312	254	215	195
Squash	0.516	0.077	0.204	0.204	1133	921	779	708
Sunflowers	0.658	0.155	0.093	0.093	753	612	517	470
Sweet potatoes	0.022	0.789	0.095	0.095	1131	920	778	707
Tomatoes	0.248	0.000	0.376	0.376	1342	1090	923	839
Vegetables, other	0.217	0.411	0.186	0.186	479	389	330	300
Wheat, spring	0.771	0.136	0.046	0.046	935	759	642	584
Wheat, winter	0.771	0.136	0.046	0.046	519	421	357	325

Table 4. Major crop irrigation management inputs for the DNDC model.

DNDC system	Fertilizer rate, lb-N/ac	Tillage
Alfalfa	15	No till
Almonds	200	No till
Apples	42	No till
Apricots	75	No till
Artichokes	215	Disk/chisel
Asparagus	90	No till
Avocados	165	No till
Barley	89	Disk/chisel
Beans, dry	90	Disk/chisel
Beans, green	128	Disk/chisel
Beets	187	Disk/chisel
Berries	160	Deep ploughing
Broccoli	175	Disk/chisel
Cabbage	244	Disk/chisel
Carrots	250	Disk/chisel
Cauliflower	245	Disk/chisel
Celery	242	Chisel/moldboard
Cherries	61	No till
Citrus, other	111	No till
Corn, grain	260	Disk/chisel
Corn, silage	245	Disk/chisel
Cotton	181	Disk/chisel
Dates	246	No till
Figs	100	No till
Fruit, other	151	No till
Garlic	253	Disk/chisel
Grapes	40	No till
Lemons	127	No till
Lettuce	188	Deep ploughing
Melons	175	Disk/chisel
Non legume hay	140	Disk/chisel
Nuts, other	201	No till
Oats	65	Disk/chisel
Olives	100	No till
Onions	216	Disk/chisel
Pasture	89	No till
Peach	151	No till
Pears	160	No till
Peppers	275	Disk/chisel
Pistachios	175	No till
Plums	125	No till
Potatoes	210	Deep ploughing
Prunes	150	No till

DNDC system	Fertilizer rate, lb-N/ac	Tillage
Safflowers	128	No till
Sorghum	100	Disk/chisel
Spinach	140	Moldboard
Squash	140	Moldboard
Sunflowers	289	No till
Sweet potatoes	90	Deep ploughing
Tomatoes	126	Deep ploughing
Vegetables, other	171	Deep ploughing
Wheat, spring	188	Disk/chisel
Wheat, winter	300	Disk/chisel

Compost application. Compost application was assumed to occur to all crops (excluding rice) once per year prior to planting or early in the growing season. Application rates are based on CDFA's guidelines (Grauver, 2016), which use the plant available nitrogen in compost to determine ranges of recommended rates of application to annual crops, trees/perennials, and rangelands. The median rate of each range is used in the modeling. Compost is added in addition to the regular fertilizer application rates as shown in Table 4. Compost ratios of C:N = 10 and C:N = 20 were chosen to represent respectively in the modeling of high nitrogen compost (C:N ≤ 11) and low nitrogen compost (C:N > 11), matching with ratios used in nutrient management implementations in COMET-Planner (Swan et al., 2016). Managed grassland was modeled both with and without grazing at an average grazing density of one cattle per acre (UC Davis, 2008) and the average nitrogen excretion rate of 93.8 kg N per head per year (ASAE, 2005). Unmanaged grassland was modeled with only grazing. The compost implementations are described in Table 5, along with the lookup Table location, providing final aggregated GHG reductions as described in the Results section.

Table 5. Compost application implementation scenarios, recommended compost application rates, and lookup Table location for final aggregated GHG reductions.

Compost Implementation	Compost carbon lb/dry ton	Compost nitrogen lb/dry ton	Compost rate dry ton/acre	Plant available nitrogen lb/acre	Lookup table location
Compost (C:N ≤ 11) Application To Annual Crops	397	40	2.9	15.5	Table 6
Compost (C:N > 11) Application to Annual Crops	540	27	4.7	8.9	Table 7
Compost (C:N ≤ 11) Application to Perennials, Orchards and Vineyards	397	40	2.2	11.8	Table 8

Compost Implementation	Compost carbon lb/dry ton	Compost nitrogen lb/dry ton	Compost rate dry ton/acre	Plant available nitrogen lb/acre	Lookup table location
Compost (C:N > 11) Application to Perennials, Orchards and Vineyards	540	27	4.7	8.9	Table 9
Compost (C:N > 11) Application to Grazed, Irrigated Pasture	397	27	4.7	8.9	Table 10
Compost (C:N > 11) Application to Grazed Grassland	397	27	4.7	8.9	Table 11

Results

For each compost application implementation in Table 4, DNDC calculates changes in carbon dioxide (as SOC), nitrous oxide, and methane emissions per crop per county compared with the baseline scenario (i.e., no compost application). These results are further aggregated into emission reduction factors for the three broader crop categories of annual crops, trees/perennials, and grasslands, per county based on Table 1. Tables 5 through 11 show the final aggregated GHG reduction estimates for the seven compost implementation scenarios, respectively.

The emission reduction factors are used to estimate a project's annual reduction in greenhouse gas emissions. Project annual reduction is calculated using the following equation:

Equation 1. Project Annual GHG Reduction for Compost Application.

$$Project\ Annual\ GHG\ Reduction = \sum A_i \times GHG_{i,c}$$

Where,

			Units
A	=	The number of project acres where a compost implementation is performed	Acre
GHG	=	The total annual greenhouse gas reduction associated with an implementation, by county	$MTCO_2e$/ac/yr
i	=	A compost application implementation	n/a
c	=	The county where the compost implementation is performed	n/a

Table 6. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions, in $MTCO_2e$/ac/yr, by county for Compost (C:N ≤ 11) Application to Annual Crops.

County	CO_2 Emissions $MTCO_2e$/ac/yr	N_2O Emissions $MTCO_2e$/ac/yr	CH_4 Emissions $MTCO_2e$/ac/yr	GHG Emissions $MTCO_2e$/ac/yr
Alameda	2.336	-0.214	0.003	2.125
Alpine	2.264	-0.131	0.001	2.134
Amador	2.236	-0.314	0.004	1.926
Butte	2.457	-0.363	0.001	2.095
Calaveras	2.334	-0.287	0.000	2.047
Colusa	2.312	-0.203	0.003	2.112
Contra Costa	2.332	-0.130	0.004	2.206
Del Norte	2.095	-0.198	-0.001	1.896
El Dorado	2.239	-0.293	0.003	1.948
Fresno	2.255	-0.086	0.001	2.170
Glenn	2.325	-0.159	0.003	2.169
Humboldt	2.215	-0.208	0.000	2.007
Imperial	2.255	-0.021	0.000	2.234
Inyo	2.218	-0.153	0.004	2.069
Kern	2.253	-0.068	0.000	2.185
Kings	2.217	-0.086	0.001	2.132
Lake	2.266	-0.143	0.002	2.125
Lassen	2.260	-0.031	0.001	2.229
Los Angeles	2.254	-0.193	0.003	2.064
Madera	2.301	-0.174	0.000	2.127
Marin	2.261	-0.202	0.001	2.060
Mariposa	2.238	-0.189	0.001	2.050
Mendocino	2.230	-0.200	0.001	2.031
Merced	2.270	-0.140	0.003	2.133
Modoc	2.265	-0.038	0.002	2.229
Mono	2.208	-0.024	0.001	2.185
Monterey	2.260	-0.183	0.002	2.079
Napa	2.264	-0.196	0.003	2.071
Nevada	2.217	-0.199	0.001	2.019
Orange	2.239	-0.217	0.003	2.025
Placer	2.256	-0.247	0.005	2.014
Plumas	2.216	-0.045	0.001	2.172
Riverside	2.149	-0.223	0.000	1.926
Sacramento	2.282	-0.153	0.005	2.134
San Benito	2.311	-0.109	0.001	2.204
San Bernardino	2.278	-0.268	0.007	2.018

County	CO_2 Emissions MTCO$_2$e/ac/yr	N_2O Emissions MTCO$_2$e/ac/yr	CH_4 Emissions MTCO$_2$e/ac/yr	GHG Emissions MTCO$_2$e/ac/yr
San Diego	2.259	-0.199	0.006	2.066
San Francisco	2.251	-0.194	0.001	2.058
San Joaquin	2.263	-0.153	0.003	2.113
San Luis Obispo	2.263	-0.154	0.003	2.112
San Mateo	2.282	-0.198	0.002	2.086
Santa Barbara	2.234	-0.269	0.003	1.967
Santa Clara	2.329	-0.236	0.002	2.095
Santa Cruz	2.245	-0.250	0.002	1.997
Shasta	2.237	-0.100	0.001	2.138
Sierra	2.227	-0.047	0.001	2.181
Siskiyou	1.997	-0.004	0.000	1.993
Solano	2.472	-0.320	0.003	2.155
Sonoma	2.273	-0.202	0.002	2.074
Stanislaus	2.254	-0.197	0.005	2.063
Sutter	2.320	-0.201	0.004	2.123
Tehama	2.276	-0.160	0.004	2.120
Trinity	2.241	-0.142	0.002	2.101
Tulare	2.258	-0.077	0.005	2.186
Tuolumne	2.240	-0.191	0.002	2.051
Ventura	2.238	-0.166	0.002	2.075
Yolo	2.315	-0.207	0.003	2.112
Yuba	2.272	-0.171	0.005	2.106

Table 7. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions by county for Compost (C:N > 11) Application to Annual Crops.

County	CO_2 Emissions MTCO$_2$e/ac/yr	N_2O Emissions MTCO$_2$e/ac/yr	CH_4 Emissions MTCO$_2$e/ac/yr	GHG Emissions MTCO$_2$e/ac/yr
Alameda	4.632	-0.187	0.006	4.451
Alpine	4.519	-0.145	0.002	4.376
Amador	4.446	-0.304	0.007	4.150
Butte	4.770	-0.277	0.003	4.496
Calaveras	4.517	-0.279	0.001	4.238
Colusa	4.604	-0.176	0.005	4.434
Contra Costa	4.620	-0.104	0.008	4.524
Del Norte	4.333	-0.251	-0.003	4.079
El Dorado	4.454	-0.289	0.006	4.171
Fresno	4.482	-0.074	0.002	4.410
Glenn	4.625	-0.137	0.007	4.495

County	CO_2 Emissions $MTCO_2e/ac/yr$	N_2O Emissions $MTCO_2e/ac/yr$	CH_4 Emissions $MTCO_2e/ac/yr$	GHG Emissions $MTCO_2e/ac/yr$
Humboldt	4.526	-0.201	0.000	4.325
Imperial	4.472	-0.020	0.000	4.452
Inyo	4.413	-0.139	0.008	4.282
Kern	4.483	-0.061	0.000	4.421
Kings	4.397	-0.078	0.003	4.322
Lake	4.557	-0.135	0.005	4.426
Lassen	4.624	-0.033	0.002	4.594
Los Angeles	4.437	-0.183	0.007	4.261
Madera	4.466	-0.168	0.001	4.298
Marin	4.535	-0.190	0.003	4.347
Mariposa	4.524	-0.189	0.003	4.338
Mendocino	4.529	-0.194	0.002	4.337
Merced	4.501	-0.126	0.008	4.383
Modoc	4.609	-0.032	0.003	4.580
Mono	4.505	-0.025	0.001	4.482
Monterey	4.498	-0.157	0.004	4.345
Napa	4.525	-0.186	0.005	4.344
Nevada	4.481	-0.203	0.002	4.280
Orange	4.453	-0.192	0.007	4.267
Placer	4.466	-0.238	0.010	4.238
Plumas	4.533	-0.051	0.002	4.484
Riverside	4.300	-0.212	0.001	4.089
Sacramento	4.534	-0.143	0.010	4.402
San Benito	4.596	-0.072	0.003	4.527
San Bernardino	4.442	-0.254	0.014	4.201
San Diego	4.440	-0.189	0.011	4.262
San Francisco	4.537	-0.180	0.002	4.359
San Joaquin	4.507	-0.133	0.007	4.381
San Luis Obispo	4.505	-0.139	0.005	4.371
San Mateo	4.566	-0.195	0.003	4.375
Santa Barbara	4.413	-0.259	0.005	4.159
Santa Clara	4.621	-0.204	0.004	4.421
Santa Cruz	4.449	-0.238	0.004	4.215
Shasta	4.612	-0.113	0.002	4.500
Sierra	4.552	-0.058	0.002	4.497
Siskiyou	4.114	-0.004	0.000	4.110
Solano	4.771	-0.238	0.006	4.538
Sonoma	4.534	-0.188	0.004	4.351
Stanislaus	4.444	-0.185	0.011	4.270

County	CO_2 Emissions $MTCO_2e/ac/yr$	N_2O Emissions $MTCO_2e/ac/yr$	CH_4 Emissions $MTCO_2e/ac/yr$	GHG Emissions $MTCO_2e/ac/yr$
Sutter	4.616	-0.176	0.007	4.447
Tehama	4.538	-0.141	0.007	4.404
Trinity	4.555	-0.138	0.005	4.422
Tulare	4.487	-0.063	0.011	4.434
Tuolumne	4.514	-0.182	0.003	4.335
Ventura	4.456	-0.148	0.005	4.313
Yolo	4.608	-0.181	0.006	4.433
Yuba	4.530	-0.161	0.009	4.378

Table 8. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions by county for Compost (C:N ≤ 11) Application to Perennials, Orchards and Vineyards.

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Alameda	1.745	-0.148	0.002	1.598
Alpine	1.645	-0.053	0.001	1.593
Amador	1.647	-0.172	0.003	1.478
Butte	1.772	-0.311	-0.001	1.460
Calaveras	1.668	-0.110	0.000	1.558
Colusa	1.731	-0.168	0.002	1.565
Contra Costa	1.734	-0.126	0.003	1.611
Del Norte	1.502	0.109	-0.002	1.608
El Dorado	1.632	-0.157	0.002	1.477
Fresno	1.708	-0.088	0.001	1.621
Glenn	1.727	-0.168	0.002	1.562
Humboldt	1.615	-0.109	0.000	1.506
Imperial	1.630	-0.082	0.000	1.548
Inyo	1.637	-0.047	0.003	1.593
Kern	1.708	-0.072	0.000	1.636
Kings	1.677	-0.051	0.001	1.627
Lake	1.671	-0.107	0.002	1.565
Lassen	1.677	-0.039	0.001	1.638
Los Angeles	1.676	-0.090	0.002	1.587
Madera	1.681	-0.072	0.000	1.610
Marin	1.678	-0.158	0.001	1.521
Mariposa	1.646	-0.176	0.001	1.470
Mendocino	1.647	-0.128	0.000	1.520
Merced	1.716	-0.117	0.002	1.601

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Modoc	1.764	-0.045	0.001	1.720
Mono	1.574	-0.019	0.000	1.556
Monterey	1.727	-0.147	0.001	1.581
Napa	1.685	-0.156	0.002	1.531
Nevada	1.616	-0.155	0.000	1.462
Orange	1.708	-0.123	0.002	1.588
Placer	1.686	-0.134	0.004	1.556
Plumas	1.589	-0.026	0.001	1.563
Riverside	1.567	-0.089	0.000	1.479
Sacramento	1.714	-0.132	0.004	1.586
San Benito	1.745	-0.123	0.000	1.622
San Bernardino	1.674	-0.081	0.006	1.599
San Diego	1.708	-0.090	0.005	1.622
San Francisco	1.660	-0.130	0.000	1.530
San Joaquin	1.701	-0.139	0.002	1.565
San Luis Obispo	1.703	-0.127	0.002	1.578
San Mateo	1.686	-0.119	0.001	1.568
Santa Barbara	1.689	-0.121	0.002	1.570
Santa Clara	1.757	-0.150	0.001	1.608
Santa Cruz	1.694	-0.126	0.001	1.569
Shasta	1.579	-0.064	0.000	1.515
Sierra	1.641	-0.033	0.001	1.609
Siskiyou	1.188	-0.002	0.000	1.187
Solano	1.781	-0.220	0.002	1.562
Sonoma	1.703	-0.146	0.001	1.558
Stanislaus	1.689	-0.105	0.004	1.589
Sutter	1.732	-0.167	0.002	1.567
Tehama	1.688	-0.153	0.003	1.538
Trinity	1.693	-0.096	0.002	1.598
Tulare	1.708	-0.096	0.004	1.616
Tuolumne	1.641	-0.203	0.001	1.440
Ventura	1.712	-0.117	0.002	1.597
Yolo	1.729	-0.166	0.002	1.565
Yuba	1.707	-0.148	0.003	1.563

Table 9. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions by county for Compost (C:N > 11) Application to Perennials, Orchards and Vineyards.

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Alameda	4.700	-0.157	0.006	4.549
Alpine	4.508	-0.058	0.002	4.452
Amador	4.527	-0.212	0.007	4.323
Butte	4.747	-0.321	-0.001	4.425
Calaveras	4.503	-0.148	0.001	4.356
Colusa	4.670	-0.180	0.004	4.495
Contra Costa	4.679	-0.129	0.008	4.558
Del Norte	4.328	0.002	-0.007	4.322
El Dorado	4.522	-0.215	0.006	4.313
Fresno	4.582	-0.090	0.003	4.495
Glenn	4.672	-0.180	0.006	4.498
Humboldt	4.559	-0.145	-0.001	4.413
Imperial	4.551	-0.090	0.000	4.461
Inyo	4.485	-0.052	0.009	4.442
Kern	4.593	-0.069	0.000	4.524
Kings	4.495	-0.054	0.004	4.446
Lake	4.613	-0.124	0.004	4.493
Lassen	4.643	-0.041	0.002	4.604
Los Angeles	4.526	-0.101	0.009	4.434
Madera	4.485	-0.088	0.001	4.398
Marin	4.610	-0.184	0.002	4.428
Mariposa	4.586	-0.201	0.002	4.387
Mendocino	4.577	-0.157	0.001	4.421
Merced	4.605	-0.126	0.009	4.489
Modoc	4.742	-0.047	0.003	4.698
Mono	4.410	-0.018	0.001	4.392
Monterey	4.641	-0.158	0.003	4.486
Napa	4.617	-0.181	0.004	4.440
Nevada	4.519	-0.196	0.001	4.324
Orange	4.583	-0.131	0.006	4.459
Placer	4.560	-0.157	0.011	4.413
Plumas	4.469	-0.027	0.002	4.444
Riverside	4.396	-0.102	0.002	4.296
Sacramento	4.634	-0.144	0.011	4.501
San Benito	4.693	-0.118	0.001	4.576
San Bernardino	4.475	-0.095	0.015	4.395

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
San Diego	4.550	-0.098	0.012	4.464
San Francisco	4.601	-0.152	0.001	4.450
San Joaquin	4.609	-0.150	0.006	4.465
San Luis Obispo	4.624	-0.138	0.005	4.490
San Mateo	4.632	-0.147	0.002	4.487
Santa Barbara	4.508	-0.136	0.005	4.377
Santa Clara	4.716	-0.158	0.002	4.561
Santa Cruz	4.566	-0.144	0.003	4.426
Shasta	4.517	-0.087	0.001	4.432
Sierra	4.574	-0.031	0.002	4.545
Siskiyou	3.365	-0.002	0.000	3.363
Solano	4.747	-0.227	0.005	4.525
Sonoma	4.631	-0.172	0.004	4.463
Stanislaus	4.523	-0.118	0.012	4.417
Sutter	4.674	-0.178	0.006	4.502
Tehama	4.622	-0.171	0.007	4.459
Trinity	4.656	-0.114	0.004	4.545
Tulare	4.596	-0.098	0.011	4.510
Tuolumne	4.575	-0.238	0.002	4.339
Ventura	4.587	-0.129	0.004	4.462
Yolo	4.667	-0.176	0.005	4.496
Yuba	4.637	-0.162	0.009	4.484

Table 10. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions by county for Compost (C:N > 11) Application to Grazed, Irrigated Pasture.

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Alpine	4.467	-0.065	0.001	4.403
Amador	4.493	-0.269	0.007	4.230
Butte	4.707	-0.205	-0.002	4.500
Calaveras	4.450	-0.181	0.001	4.269
Colusa	4.649	-0.179	0.004	4.474
Contra Costa	4.655	-0.111	0.007	4.551
Del Norte	4.367	-0.216	-0.008	4.143
El Dorado	4.489	-0.267	0.005	4.227
Fresno	4.583	-0.109	0.004	4.477
Glenn	4.653	-0.183	0.006	4.476
Humboldt	4.569	-0.144	-0.002	4.424

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Imperial	4.626	-0.060	0.000	4.566
Inyo	4.450	-0.089	0.008	4.370
Kern	4.582	-0.087	0.000	4.494
Kings	4.498	-0.072	0.007	4.432
Lake	4.600	-0.130	0.004	4.474
Lassen	4.618	-0.035	0.002	4.585
Los Angeles	4.505	-0.126	0.012	4.391
Madera	4.449	-0.126	0.000	4.324
Marin	4.580	-0.215	0.001	4.366
Mariposa	4.583	-0.257	0.002	4.328
Mendocino	4.580	-0.155	0.001	4.426
Merced	4.589	-0.156	0.012	4.445
Modoc	4.646	-0.050	0.003	4.599
Mono	4.420	-0.020	0.000	4.401
Monterey	4.579	-0.174	0.003	4.408
Napa	4.583	-0.178	0.004	4.410
Nevada	4.491	-0.267	0.000	4.225
Orange	4.572	-0.181	0.006	4.397
Placer	4.503	-0.186	0.010	4.327
Plumas	4.481	-0.034	0.001	4.449
Riverside	4.482	-0.165	0.001	4.317
Sacramento	4.596	-0.152	0.011	4.455
San Benito	4.646	-0.114	0.001	4.533
San Bernardino	4.439	-0.157	0.015	4.297
San Diego	4.503	-0.112	0.012	4.403
San Francisco	4.579	-0.186	0.000	4.394
San Joaquin	4.585	-0.169	0.006	4.423
San Luis Obispo	4.580	-0.146	0.004	4.438
San Mateo	4.594	-0.150	0.002	4.446
Santa Barbara	4.488	-0.149	0.005	4.343
Santa Clara	4.652	-0.139	0.002	4.515
Santa Cruz	4.491	-0.152	0.003	4.342
Shasta	4.539	-0.104	0.001	4.435
Sierra	4.565	-0.035	0.002	4.531
Siskiyou	3.345	-0.002	0.000	3.343
Solano	4.706	-0.167	0.004	4.543
Sonoma	4.585	-0.160	0.003	4.428
Stanislaus	4.503	-0.157	0.012	4.358
Sutter	4.655	-0.183	0.006	4.478

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Tehama	4.590	-0.207	0.007	4.390
Trinity	4.607	-0.123	0.004	4.488
Tulare	4.580	-0.118	0.011	4.472
Tuolumne	4.573	-0.291	0.001	4.283
Ventura	4.571	-0.166	0.004	4.409
Yolo	4.652	-0.182	0.005	4.475
Yuba	4.592	-0.193	0.009	4.408

Table 11. Estimated carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and total greenhouse gas (GHG) emission reductions by county for Compost (C:N > 11) Application to Grazed Grassland.

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Alpine	4.437	-0.024	0.003	4.416
Amador	4.447	-0.137	0.008	4.319
Butte	4.656	-0.102	0.001	4.555
Calaveras	4.410	-0.123	0.000	4.287
Colusa	4.576	-0.051	0.006	4.531
Contra Costa	4.573	-0.051	0.009	4.531
Del Norte	4.379	-0.157	-0.007	4.216
El Dorado	4.463	-0.155	0.007	4.315
Fresno	4.447	-0.020	0.003	4.430
Glenn	4.584	-0.063	0.007	4.528
Humboldt	4.538	-0.121	-0.001	4.416
Imperial	4.452	-0.002	0.000	4.450
Inyo	4.409	-0.002	0.010	4.417
Kern	4.471	-0.007	0.000	4.463
Kings	4.388	-0.008	0.006	4.385
Lake	4.545	-0.045	0.005	4.505
Lassen	4.538	-0.014	0.003	4.526
Los Angeles	4.426	-0.033	0.013	4.407
Madera	4.401	-0.032	0.000	4.369
Marin	4.541	-0.092	0.003	4.451
Mariposa	4.533	-0.104	0.004	4.432
Mendocino	4.499	-0.076	0.002	4.425
Merced	4.484	-0.047	0.013	4.451
Modoc	4.615	-0.023	0.004	4.596
Mono	4.521	-0.097	0.005	4.429
Monterey	4.530	-0.065	0.005	4.471

County	CO_2 Emissions MTCO2e/ac/yr	N_2O Emissions MTCO2e/ac/yr	CH_4 Emissions MTCO2e/ac/yr	GHG Emissions MTCO2e/ac/yr
Napa	4.469	-0.176	0.002	4.296
Nevada	4.462	-0.052	0.008	4.417
Orange	4.478	-0.066	0.011	4.424
Placer	4.345	-0.014	0.003	4.333
Plumas	4.368	-0.003	0.000	4.365
Riverside	4.542	-0.049	0.012	4.506
Sacramento	4.572	-0.066	0.003	4.509
San Benito	4.395	-0.034	0.016	4.378
San Bernardino	4.440	-0.035	0.014	4.418
San Diego	4.554	-0.099	0.001	4.457
San Francisco	4.514	-0.058	0.007	4.463
San Joaquin	4.484	-0.099	0.006	4.391
San Luis Obispo	4.570	-0.088	0.003	4.485
San Mateo	4.397	-0.060	0.006	4.343
Santa Barbara	4.594	-0.092	0.004	4.506
Santa Clara	4.477	-0.085	0.004	4.396
Santa Cruz	4.443	-0.086	0.002	4.358
Shasta	4.496	-0.007	0.003	4.492
Sierra	3.348	-0.001	0.000	3.347
Siskiyou	4.624	-0.063	0.006	4.567
Solano	4.539	-0.054	0.005	4.490
Sonoma	4.419	-0.048	0.013	4.385
Stanislaus	4.588	-0.073	0.008	4.523
Sutter	4.545	-0.077	0.008	4.476
Tehama	4.557	-0.053	0.005	4.509
Trinity	4.474	-0.032	0.013	4.454
Tulare	4.517	-0.123	0.003	4.397
Tuolumne	4.456	-0.047	0.006	4.415
Ventura	4.575	-0.068	0.007	4.513
Yolo	4.557	-0.062	0.010	4.505
Yuba	4.521	-0.097	0.005	4.429

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