Compost Application Rates for California Croplands and Rangelands for a CDFA Healthy Soils Incentives Program

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Executive Summary

As part of Governor Brown's Healthy Soils Initiative, the California Department of Food and Agriculture (CDFA) is planning to establish a financial incentive program for California's farmers and ranchers to implement practices that improve soil health and reduce greenhouse gas (GHG) emissions. These incentives, as proposed, would be based on the USDA Natural Resources Conservation Service (NRCS) Conservation Practices that are included in COMET-Planner. COMET-Planner is a tool developed by NRCS to estimates GHG reductions from management practice changes. CDFA recognizes that the Air Resources Board (ARB) is responsible for developing the quantification methodology (QM) associated with any program funded through the California Climate Investments program, also known as the Greenhouse Gas Reduction Fund. As such, this report describes analyses that may support the development of a QM for the CDFA incentive program, rather than furnishing the QM tool that will be used.

One agricultural practice with considerable soil health improvement and GHG reduction potential is not yet represented as a stand-alone Conservation Practice in the COMET-Planner tool: the application of compost to croplands and rangelands, an important conservation practice that can improve soil health. In order to make this management practice included in any future incentive program by CDFA, compost application rates that would be cost-shared by the program need to be established.

At the recommendation of the Environmental Farming Act Science Advisory Panel, CDFA convened a subcommittee of scientists to propose best-available science-based application rates for compost. This subcommittee proposed distributing composts into two major categories: those with higher nitrogen (C:N ≤ 11) and those with lower nitrogen (C:N > 11) content. The group also proposed dividing California cropping systems into two major types (annual crops and tree crops) and considering croplands and rangelands separately.

Based on scientific literature reviews, the recommendations of the subcommittee, and public comments, a maximum application rate of 8 moist (i.e., as purchased) tons of compost/acre/year was determined. Application rates of moist compost application for croplands were: for annual crops, 3-5 tons/acre/year for higher nitrogen (C:N ≤ 11) compost and 6-8 tons/acre/year for lower nitrogen (C:N > 11) compost; and for tree crops, 2-5 tons/acre/year for higher nitrogen compost and 6-8 tons/acre/year for lower nitrogen compost.

Because specific field data on rangeland compost application in California is still very limited, very conservative estimates were used in setting rangeland application rates to 6-10 tons/acre of lower nitrogen compost only. Priority site types for these applications have been identified, consistent with public comment, and include rangelands that have been depleted of their baseline soil organic matter through a variety of agronomic practices or that have been otherwise managed such that natural plant communities are either no longer present or are of a type that would not be threatened by soil amendments. It is vital to continue documenting effects of this practice and adjusting application rates according to site specific conditions. Higher application rates may be possible once more data is acquired through ongoing studies of this practice.

Additional information on the science of how these rates were determined is described in this report. Also, we note that producers participating in the program would be able to apply compost at higher rates than those put forward here; however, the CDFA financial incentive would be limited to the rates in this report.

Introduction

In the 2015-16 proposed budget, Governor Brown recognized the importance of soil health and directed the California Department of Food and Agriculture (CDFA) to coordinate a new initiative to support and enhance this critical resource. The budget language stated "As the leading agricultural state in the nation, it is important for California's soils to be sustainable and resilient to climate change. Increased carbon in soils is responsible for numerous benefits including increased water holding capacity, increased crop yields and decreased sediment erosion. In the upcoming year, the Administration will work on several new initiatives to increase carbon in soil and establish long term goals for carbon levels in all California's agricultural soils. CDFA will coordinate this initiative under its existing authority provided by the Environmental Farming Act".

Consistent with the Governor's initiative, now titled the Healthy Soils Initiative, CDFA worked with several state agencies to identify short and long-term actions that could improve soil health in California to ensure agricultural sustainability and food security (https://www.cdfa.ca.gov/EnvironmentalStewardship/ pdfs/ShortTermActions.pdf). One of the actions identified was to incentivize management practices that build the carbon content in soils. Increasing the carbon content of soils has been scientifically shown to lead to greater agricultural sustainability and ensure food security, especially in light of climate change. CDFA plans to implement a cost-share incentives program using Conservation Practice Standards established by the United States Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS). The CDFA program would include soil health-promoting management practices that also reduce greenhouse gas (GHG) emissions. Most candidate practices that could meet these goals are identified in the recently developed COMET-Planner tool[1]. COMET-Planner provides estimates of GHG reductions from each included practice, which serve as an input to the California Air Resources Board (ARB)'s process of developing a quantification methodology (QM) that will meet the needs of the California Climate Investments program.

One agricultural practice with considerable soil health improvement and GHG reduction potential is the application of compost to croplands and rangelands. Incentivizing the use of this practice can indirectly achieve large GHG emission reductions[2] by increasing demand, spurring expansion of composting facilities and organic waste diversion from landfills that produce methane. Methane is a GHG with a 100-year global warming potential 28 times that of carbon dioxide. Aerobic composting allows the carbon in plant and animal source materials to be stabilized into carbon compounds that generally decompose slowly after the compost is applied to land. Land application of compost also directly stimulates biological processes, including increases in soil microbial and plant biomass[3,4], that sequester carbon into stable long-term organic matter fractions[5,6]. Increases in these organic matter fractions offer numerous benefits such as increasing the water and nutrient retention capacity of soils, providing a reservoir of nutrients for plants, improving aeration, improving water infiltration, reducing soil erosion, and supporting the abundance and diversity of soil organisms, which can improve plant health.

CDFA must determine application rates of compost that would be supported by an incentive program. CDFA will not be able to support unlimited rates of compost application requested by farmers and ranchers given the limited amount of funding available as incentives, as well as the need to ensure that environmental concerns are addressed. The amount of anticipated greenhouse gas reduction corresponding to developed application rates can then be estimated based on a model recognized by ARB[7].

CDFA recognizes that ARB is ultimately responsible for developing the quantification methodology (QM) associated with any program funded through the California Climate Investments program, also known as funding from the Greenhouse Gas Reduction Fund. As such, this report describes some quantitative analyses that may support the development of a QM for the CDFA incentive program, rather than furnishing the QM tool that will be used.

Methodology

On July 17, 2015, CDFA convened a meeting of the Environmental Farming Act Science Advisory Panel (EFA SAP) to discuss the application of compost to California croplands and rangelands. The EFA SAP is a group of farmers and scientists who provide scientific guidance to the Secretary of CDFA and is a platform for public comment. The EFA SAP functions under the authority of the Environmental Farming Act of 1995 (https://www.cdfa.ca.gov/oefi/efasap/docs/Environmental_Farming_Act.pdf). The July 17th meeting was open to the public and attended by a variety of stakeholders. Attendees at the meeting recommended that CDFA convene a subcommittee of compost experts (from academia and state agencies) to evaluate and propose compost application rates, which could then be considered for review by the EFA SAP, subject to public comment and proposed to the Secretary of CDFA to implement as part of any future Healthy Soils Incentive Program.

On August 28, 2015, CDFA convened a meeting of a compost subcommittee. The group consisted of university researchers in soil science, compost management and agronomy and included scientists from several pertinent state agencies such as CalRecycle, CDFA and the Central Valley Regional Water Quality Control Board (a complete list of participants can be found at the end of this report). The goal of this meeting was to determine compost application rates that could be supported by a CDFA Incentives Program given the diversity of cropping systems in California. A second meeting of the subcommittee was held on September 30, 2015. Several literature reviews were conducted to evaluate the best available science that would support compost application rates for a CDFA Incentives Program for discussion at the two subcommittee meetings.

A second Environmental Farming Act Science Advisory Panel (EFA SAP) meeting on this topic was convened on January 15, 2016. A draft report of the results from the subcommittee meetings was presented to the members. Public comment on the report was solicited at this meeting, as well as through a four-week public comment period extending through February 12, 2016.

The Results section below summarizes the proposed compost application rates recommended by the subcommittee and takes into consideration public comments received.

Results

Definition of compost eligible for the program

For the purposes of the CDFA Healthy Soils Incentives Program, compost is defined as all of the following:

- The product resulting from the controlled biological decomposition of organic wastes that are source separated from the municipal solid waste stream, or which are separated at a centralized facility. Feedstocks may include green materials, food materials, wood waste, yard trimmings, agricultural materials or biosolids as defined in 14 CCR Section 17852 (www.calrecycle.ca.gov/laws/regulations/title14/ch31.htm)
- Must be produced by a facility permitted or otherwise authorized by state and local authorities that can demonstrate compliance with all state regulations regarding inspection of incoming feedstocks, finished-product testing requirements including the Process to Further Reduce Pathogens (PFRP) as described in 14 CCR Section 17868.3, maximum metal concentrations for heavy metals per 14 CCR Section 17868.2, and physical contamination limits per 14 CCR Section 17868.3.1. (14 CCR Section 17868: www.calrecycle.ca.gov/laws/regulations/title14/ch31a5.htm#article7)
- Note: STA certified or CDFA-OIM compost is recommended. STA certified compost means the compost has been tested for numerous product parameters by a STA-certified lab which uses standardized testing methodologies (TMECC, developed by the United States Composting Council), and the results (in a technical data sheet) are reported to the compost producer.

Composts to which biochar was added *during the composting process* as a process amendment are also eligible for the program as long as they meet all of the requirements above. Biochar materials alone or biochar materials that have been added to compost in contexts other than as an amendment to facilitate the composting process are not eligible for this incentives program. The reason for excluding biochar in the CDFA Incentive Program at this time is because regulatory standards are in the process of being developed and there are few experimental field trials that examine the application rate of biochar along with evaluating its benefits and limitations.

Each incentive program participant must ensure that the compost products they use are in compliance with any additional regulations that may apply to their particular production system. These include, but are not limited to, National Organic Program guidance for USDA certified organic growers and Food Safety Modernization Act (FSMA) Produce Safety Rule requirements for growers of fresh produce that is covered under this Rule.

Determining application rates

The subcommittee meeting on August 28, 2015, reached consensus that there is too much variation in the scientific data within both “croplands” and “compost” to define a single application rate to all agricultural lands. The subcommittee felt that “croplands” could be usefully divided into annual crops and tree crops and that both conventional and organic management systems should be considered for each of these production systems. Rangelands have different considerations and warranted their own separate category. Compost, as defined above can be divided into two further categories (carbon [C]: nitrogen [N] ratio [C:N ratio] less than 11 and C:N ratio greater than 11). This differentiation separates composts that provide more nitrogen at a faster rate (low C:N) and those that provide less nitrogen at a slower rate (high C:N).

C:N typically reflects both the feedstocks used to produce compost (e.g., manure-based composts tend to have lower C:N than plant waste-based composts) and the maturity of the compost product (immature composts can have higher C:N than mature composts). Because only "fully finished" composts will be eligible for this program, C:N differences among *eligible* composts will primarily relate to differences in the feedstocks used to produce them. In a data set of 1364 southwestern U.S. compost samples (shared with CalRecycle by Soil Control Labs, Watsonville, CA), C:N correlated with compost percent nitrogen (r = -0.44). Based on this observation and the recommendation of the subcommittee, C:N appears to be a reasonable metric on which to base compost application rates. In total, the subcommittee identified ten application rates for a CDFA Incentives Program on building soil carbon (Figure 1).

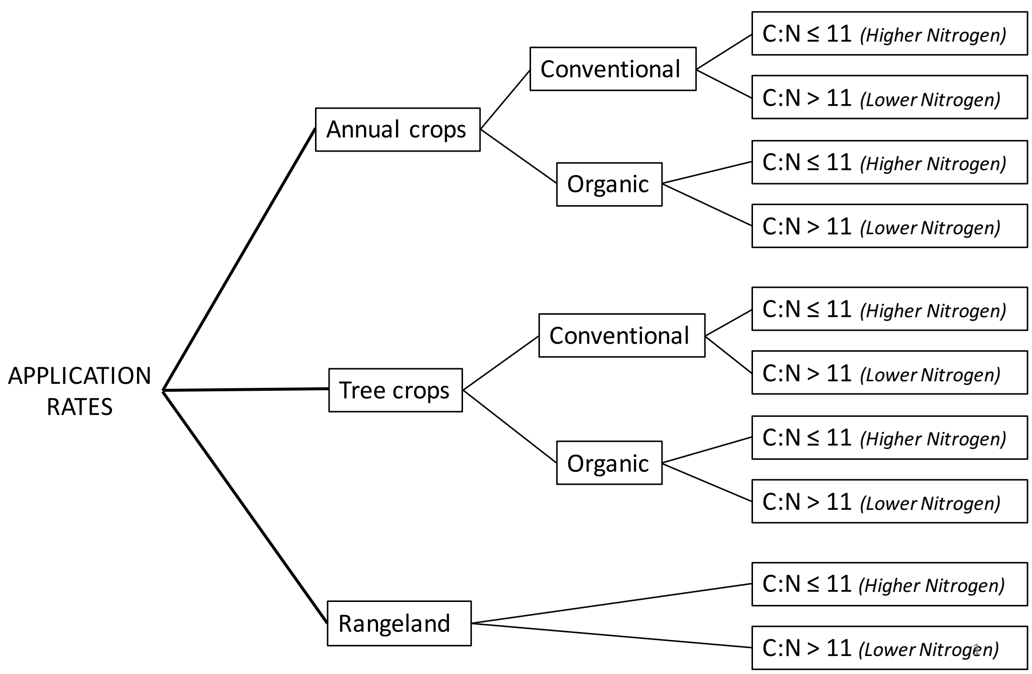


Figure 1. Distribution of application rates to define, as established at August 28, 2015 subcommittee meeting.

The subcommittee agreed to setting the upper limit of each application rate range based on best-available scientific data on the potential environmental impact(s) of greatest concern. This strategy is not meant to imply that the primary result of compost application to croplands and rangelands would be one of environmental impact; rather, the intent was to focus on the significant soil health benefits that compost has been shown to provide while at the same time minimizing potential for environmental impacts.

Compost application rates for croplands

For croplands, the subcommittee determined leaching of nitrogen (in the form of nitrate) from compost to ground water to be the environmental impact of greatest concern. Many participating growers in the CDFA Incentive Program may choose to reduce their synthetic nitrogen fertilizer applications as they gain experience with the nitrogen content in composts to minimize nitrates in surface and groundwater; however, no assumptions about such behaviors were made when developing compost application rates.

Composts contain a small (often < 0.1%) percentage by weight of nitrate as well as larger (often 1-3%) percentages by weight of other nitrogen compounds that could eventually be converted to nitrate by resident soil microbes. A scientific literature review was completed to estimate the total nitrogen available over time in the two types of composts.

Estimating nitrogen mineralization from compost: Nitrogen in compost can be divided into three main types. The majority (usually > 95%) of compost N is organically bound (attached to carbon). Most compost also contains small amounts of inorganic (non-carbon based) N in the form of nitrate (NO_3^-) and ammonium (NH_4^+). Resident microbes can quickly convert ammonium to nitrate, and can slowly convert organic nitrogen to ammonium and then nitrate over time (Figure 2). Scientific literature was reviewed to develop estimates of the rate ammonium + nitrate release by compost.

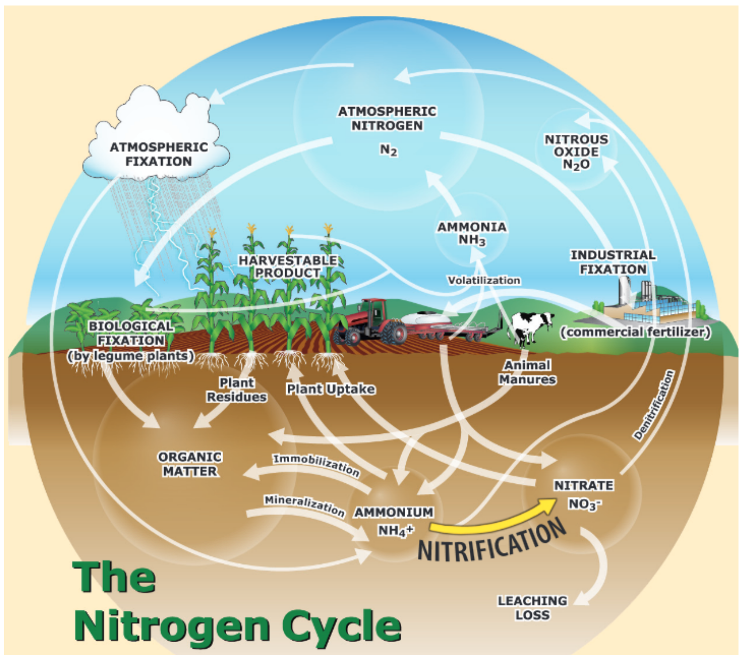
In addition to slowly releasing ammonium + nitrate, compost will likely alter soil properties such that less nitrate leaches into groundwater per pound of ammonium + nitrate in the soil as compared to unamended fields[8,9]. For example, compost generally improves soil water holding capacity, such that less water – potentially carrying nitrate – may leach below the crop root zone in compost-amended fields. However, because the amount of this reduction is highly dependent on soil type[9] along with a range of other management factors, we could not reliably quantify it at this time.

Estimating the rate of ammonium + nitrate release by compost requires three pieces of information. They are: 1. the amount (by weight) of ammonium + nitrate in the compost, 2. the amount (by weight) of organically-bound nitrogen in the compost, and 3. a model for the rate at which this organically-bound nitrogen will be converted (mineralized) to ammonium + nitrate. Estimates for the first two information needs above were obtained using lab analyses for 1364 Southwestern U.S. compost samples from a variety of feedstocks that was provided by Soil Control Labs (Watsonville, CA). Composts were first divided into two categories (C:N ≤ 11 and C:N > 11) and average values of these quantities were calculated for each category separately (Table 1).

Table 1. Average (median) pounds (lbs) of nitrogen per ton of dry compost and average moisture content for higher nitrogen (C:N ≤ 11) and lower nitrogen (C:N > 11) compost types, as calculated from data on 1364 compost samples provided by Soil Control Labs (Watsonville, CA).

	Higher N compost (C:N ≤ 11)	**Lower N compost (C:N > 11)**
Lbs N as ammonium (NH_4^+)	1.43	0.51
Lbs N as nitrate (NO_3^-)	0.12	0.07
Lbs N as organically-bound N	38.12	26.43
Moisture content	27.11%	34.14%

A model for the rate at which organically-bound nitrogen in compost is mineralized to ammonium + nitrate was developed. The model was developed using information from publications that synthesized many individual studies and/or studies that were specific to California[10–15]. Publications that met these criteria were fairly consistent in their mineralization rate estimates, suggesting that these estimates are a reasonable basis on which to determine application rates. However, as additional California-specific studies become available, these rates should be revisited. In addition, it would be useful to conduct a formal meta-analysis of all available studies, through which the influence of factors such as climate and compost type could be quantified, and an alternative method of calculating California-appropriate estimates could be employed using those relationships. Such a meta-analysis was not feasible with the resources available for this study.



Source: IPNI publication number 4; www.ipni.net/publications

Figure 2. The nitrogen cycle showing that organically-bound nitrogen (such as that in plant residues and animal manures) is mineralized to ammonium and nitrate.

For compost with higher nitrogen (C:N ≤ 11), studies suggested that 5-15% (average ≈ 10%) of the organically-bound nitrogen would be mineralized in the first year of application. Each subsequent year, additional remaining organically-bound nitrogen would be mineralized, at a rate that would decline by half each year to a minimum of approximately 2% until all of the organic N in the compost had been consumed[10]. As an example, approximately 10% of the organically-bound nitrogen would be mineralized in the first year, 5% of the remaining organically-bound nitrogen in the second year, 2.5% of the remaining organically-bound nitrogen in the third year, and 2% of the remaining organically-bound nitrogen in the fourth year and subsequent years. For compost with lower nitrogen (C:N > 11), studies suggested that 2-7% (average ≈ 5%) of the organically-bound nitrogen would be mineralized in the first year, with a similar pattern of mineralization in subsequent years, including a 2% minimum. At a second scientific subcommittee meeting held on September 30, 2015, the subcommittee verified that the model was in agreement with existing scientific findings.

Comparing nitrogen from compost to recommended plant nitrogen requirements: The amount of ammonium + nitrate released from compost in a given year following its application can be estimated and compared with plant required nitrogen recommendations. Plant required nitrogen recommendations are available on CDFA's Fertilizer Research and Education Program (FREP) and are accessible at http://apps.cdfa.ca.gov/frep/docs/Guidelines.html. For this analysis, plant required nitrogen recommendations were averaged across two major crop types: annual crops and tree crops. For annual fruit and vegetable crops (including processing tomatoes, broccoli, lettuce, strawberries, cauliflower, and corn), an average of 161 lbs of nitrogen per acre per year was calculated (with a high of 270 lbs/acre for corn). For established tree crops (including established almonds, walnuts, citrus, pistachios, and plums), an average of 115 lbs of nitrogen per acre per year was calculated (with a high of 380 lbs/acre for almonds). Using these values, the amount of ammonium + nitrate released from compost can be expressed in units of percentage of total plant required nitrogen represented by compost for annual and tree crops (Box 1).

Box 1. Example of calculations to determine the percentage of total plant required nitrogen represented by compost for tree or annual crops. In this report, application rate recommendations for compost are shown in terms of "tons moist compost" to allow easy comparison with current application rates used by growers. However, percent moisture varies widely among composts. Actual incentivized rates will be in terms of "tons dry compost", with the grower and compost facility responsible for determining the equivalent moist compost application rate based on the percent moisture content of the specific compost purchased.

Example 1: Apply lower N compost (C:N > 11) to tree crop

- N released by compost in year 1: 1.91 lbs per ton dry compost [ammonium-N + nitrate-N + 5% of organically-bound N]
- Average total N required for tree crops: 115 lbs/acre
- Average % moisture of lower N compost = 34.14%

- If applying **5 moist tons** of lower N compost / acre (1 ton (U.S. Short Ton) = 2000 lbs):
  - 5*(1- 0.3414) = 3.29 tons dry compost equivalent
  - 3.29 * 1.91 = 6.27 lbs N applied per acre
  - 6.27 / 115 = *5.5% of total required N added by compost*

Example 2: Apply higher N compost (C:N ≤ 11) to annual crop

- N released by compost in year 1: 5.36 lbs per ton dry compost [ammonium-N + nitrate-N + 10% of organically-bound N]
- Average total N required for annual crops: 161 lbs/acre
- Average % moisture of higher N compost = 27.11%

- If applying **4 moist tons** of higher N compost / acre (1 ton (U.S. Short Ton) = 2000 lbs):
  - 4*(1- 0.2711) = 2.92 tons dry compost equivalent
  - 2.92 * 5.36 = 15.6 lbs N applied per acre
  - 15.6 / 161 = *9.7% of total required N added by compost*

Table 2. Proposed compost application rates for croplands. The rates to use for proposed CDFA Incentives Program are the "equivalent dry compost application rates"(†), which should be converted to corresponding moist compost application rates on a batch-specific basis using moisture data from the compost facility. *As C:N ratio rises above 24, the likelihood of N immobilization increases, which may lead to decreased N availability for crops. As compost C:N increases, monitoring becomes increasingly important to ensure adequate crop N supply.

Crop Type	Compost Type	Moist Compost Application Rate (tons/acre)	Equivalent Dry Compost Application Rate (tons/acre)†
Annual	Higher N (C:N ≤ 11)	3 – 5	2.2 – 3.6
Annual	Lower N (C:N > 11)*	6 – 8	4.0 – 5.3
Tree	Higher N (C:N ≤ 11)	2 – 4	1.5 – 2.9
Tree	Lower N (C:N > 11)*	6 – 8	4.0 – 5.3

At the second subcommittee meeting on September 30, 2015, the scientists supported the proposed rates in Table 2, with minor modifications, to be used in a CDFA Incentive Program. These rates would represent 6.1 - 13.6% of total plant required N, broken down as follows: 7.3 – 12.1% for higher N compost on annual crops, 6.1 – 8.1% for lower N compost on annual crops, 6.8 – 13.6% for higher N compost on tree crops, and 8.6 – 11.4% for lower N compost on tree crops.

At the present time, CDFA does not plan on incentivizing the same applicant to apply compost in multiple successive years given uncertainties in funding. Potential nutrient inputs from compost application in multiple successive years, due to the slow-release nature of compost nutrients, could become an environmental concern. It should be noted however, that the percentage of plant nitrogen requirements would be double the values stated above in the eighth and fifth successive year of application for higher nitrogen and lower nitrogen composts, respectively. The values would be triple those stated above in the 17^{th} and ninth successive year of application for higher nitrogen and lower nitrogen composts, respectively.

The application rates listed in Table 2 do not limit farmers from adding additional compost. The listed application rates have been established solely to support a CDFA Incentive Program. Participating growers should be required to test soil nitrogen and phosphorus levels in fields to which they are applying compost at least annually, to understand its effects on nutrient supply and be able to adjust subsequent management accordingly with carbon sequestration management practices.

Compost application rates for rangelands

In California, the benefits and potential drawbacks of compost application have received less attention on rangelands compared to croplands. Results from only two northern California experiments (Yuba County and Marin County, average annual precipitation 730 mm and 950 mm respectively) have been published[4,16,17]. At these sites, adding 31 tons/acre of compost (C:N = 11) resulted in C sequestration of 51 ± 77 to 333 ± 52 g C/m^2 over three years, in addition to the carbon directly added by the amendment[4]. The scientific subcommittee cautioned against extrapolating these results to all California rangelands, given the considerable diversity of climates and soils throughout the state[18,19]. Thus, while these initial northern California results are encouraging, studies at additional sites across California's climate and soil gradients are necessary to understand the range of potential carbon sequestration rates that might be achieved.

Scientific subcommittee discussions of potential environmental impacts of compost application to rangeland led to three concerns: 1. the potential for increased nitrate leaching to groundwater, 2. the potential for declines in plant diversity since nutrient addition could disproportionately favor certain plant species and 3. the stream-dissected sloping rangeland landscape, combined with the nitrogen and phosphorus content in many composts, raised the concern of nutrient movement into surface water streams. For reasons detailed in the "Primary potential environmental impacts of compost application to rangelands" section below, we used the second concern (potential plant diversity decline) as a means of setting the upper application rate for rangeland and noted potential methods of addressing the other two concerns.

Defining rates based on potential plant diversity impacts: A literature review of organic amendment applications to rangelands was initiated. Studies meeting the following criteria were included in the review: 1. organic amendment had been added to a semi-arid or Mediterranean-climate rangeland community (mostly grasslands, sometimes with scattered trees or shrubs), 2. authors reported the percent nitrogen of the amendment with adequate information to assign it to the "high N" (C:N ≤ 11) or "low N" (C:N > 11) category, and 3. plant community diversity had been measured at some point after adding the amendment and compared to that of comparable control plot(s). In total, nine non-redundant studies fit the review criteria; five of which had used non-composted amendments. Most of the studies (including those of composted and non-composted amendments) had applied the amendment at multiple rates, providing 35 data points (from the number of studies times the application rate), nine of which represented composted amendments. Across these studies, the plant community was observed an average of four years after amendment application. Using the C:N and percent nitrogen data provided in the studies, the same mineralization model used for croplands (described above) was then used to estimate the cumulative amount of available nitrogen that would have been released from the amendment by the time the plant diversity data was collected. The data points were then sorted by this estimate of nitrogen released (Table 3).

Table 3. Literature review of organic amendment additions to semi-arid rangelands, sorted by N released at time of plant diversity measurement.

Amendment Type	Study	Mg/ha applied	Amendment N Category	Years between application & measurement	Inorganic N (lbs per ton compost)	Organic N (lbs per ton compost)	Available lbs N released/acre at time of measurement	Plant diversity decrease
non-composted	Pierce et al. 1998[20]	5	Lower N	2	0.34	0.24	0.52	N
non-composted	Pierce et al. 1998[20]	10	Lower N	2	0.34	0.24	1.04	N
non-composted	Pierce et al. 1998[20]	15	Lower N	2	0.34	0.24	1.56	N
non-composted	Pierce et al. 1998[20]	20	Lower N	2	0.34	0.24	2.08	N
non-composted	Pierce et al. 1998[20]	25	Lower N	2	0.34	0.24	2.60	N
non-composted	Pierce et al. 1998[20]	30	Lower N	2	0.34	0.24	3.12	N
non-composted	Pierce et al. 1998[20]	35	Lower N	2	0.34	0.24	3.64	N
non-composted	Pierce et al. 1998[20]	40	Lower N	2	0.34	0.24	4.16	N
non-composted	Sullivan et al. 2006[21]	2.5	Higher N	13	7.48	82.32	17.21	N
compost	Kowaljow et al. 2010[22]	40	Lower N	2	0.48	14.92	18.57	N
compost	Kowaljow et al. 2010[22]	40	Lower N	2	0.96	13.04	22.58	N
compost	Pedrol et al. 2010[23]	20	Lower N	0.5	2.36	43.44	26.65	N
non-composted	Sullivan et al. 2006[21]	5	Higher N	13	7.48	82.32	34.42	N
non-composted	Stavast et al. 2005[24]	12	Higher N	2	2.60	31.60	37.59	Y
compost	Kowaljow et al. 2010[22]	40	Lower N	2	1.06	29.94	38.41	N
compost	Martínez et al. 2003[25]	40	Lower N	3	1.82	33.38	54.82	Y
compost	Kowaljow et al. 2010[22]	40	Lower N	2	2.68	34.32	61.24	N
non-composted	Sullivan et al. 2006[21]	10	Higher N	13	7.48	82.32	68.85	Y
compost	Martínez et al. 2003[25]	80	Lower N	3	1.82	33.38	109.64	Y
non-composted	Sullivan et al. 2006[21]	21	Higher N	13	7.48	82.32	144.58	Y
compost	Ryals et al. 2016[26]	70	Higher N	3	2.38	35.02	146.72	N
non-composted	Martínez et al. 2003[25]	40	Higher N	3	4.02	48.98	158.30	Y
non-composted	Fresquez et al. 1990[27]	22.5	Higher N	3	7.38	89.82	163.30	N
compost	Martínez et al. 2003[25]	120	Lower N	3	1.82	33.38	164.46	Y
non-composted	Jurado-Guerra et al. 2013[28]	30	Higher N	2	6.22	75.78	167.89	Y
non-composted	Sullivan et al. 2006[21]	30	Higher N	13	7.48	82.32	206.54	Y
non-composted	Jurado-Guerra et al. 2013[28]	45	Higher N	2	6.22	75.78	251.83	Y
non-composted	Martínez et al. 2003[25]	80	Higher N	3	4.02	48.98	316.60	Y
non-composted	Fresquez et al. 1990[27]	45	Higher N	3	7.38	89.82	326.61	Y
non-composted	Jurado-Guerra et al. 2013[28]	60	Higher N	2	6.22	75.78	335.77	Y
non-composted	Stavast et al. 2005[24]	107	Higher N	2	2.60	31.60	343.17	Y
non-composted	Jurado-Guerra et al. 2013[28]	75	Higher N	2	6.22	75.78	419.72	Y
non-composted	Martínez et al. 2003[25]	120	Higher N	3	4.02	48.98	474.90	Y
non-composted	Jurado-Guerra et al. 2013[28]	90	Higher N	2	6.22	75.78	503.66	Y
non-composted	Fresquez et al. 1990[27]	90	Higher N	3	7.38	89.82	653.21	Y

Three nitrogen application rate categories were observed in Table 3; 1. at approximately 35 lbs available N/acre, impacts to native plant species are unlikely (0% of data points showed impact), 2. between 35 and 164 lbs available N/acre, impacts are probable (60% of data points showed impact) and 3. above approximately 164 lbs available N/acre, impacts are highly likely (100% of data points showed impact). Based on these findings, one strategy for minimizing impacts could be to only allow lower nitrogen amendments to be used on rangelands. Another strategy could be to set application rates so that the available nitrogen provided by compost would be less than 35 lbs/acre. Combining these two strategies and using a five-year post-application time frame for calculating cumulative available N, the impact threshold would occur at approximately 13 moist tons/acre of lower nitrogen compost. Given that this figure is close to the upper limit of lower N compost application rates for croplands (8 moist tons/acre) proposed to date (Table 2), rates for all agricultural lands were kept consistent (Table 4).

However, this impact minimization strategy should still be viewed with caution because literature review studies differed in vegetation (e.g., perennial instead of annual dominated) and climate from California's rangelands. Given this uncertainty, a complementary strategy would be to consider the risk to native plant diversity from the perspective of the site to which compost would be added. For instance, some types of rangeland are especially sensitive to nutrient addition and/or contain high concentrations of rare species. For example, impacts on species of conservation concern in serpentine grasslands have occurred at N addition rates much lower than the threshold rates suggested by the literature review.[29–31] Discussions with the scientific subcommittee, as well as public comments from California rangeland experts, suggested that compost application to some types of rangeland clearly posed a higher risk.

Based on this information, we grouped potential rangeland site types into three categories: 1. "priority" site types, where compost application should have the least impact on native plant diversity; 2. "evaluate" site types, where compost application at the proposed rates may have an impact; and 3. "ineligible" site types, where compost application, even at low rates, would be likely to impact native plant diversity (Table 5). Proposals to add compost to "priority" site types would rank higher than similar proposals for "evaluate" site types, while proposals to add compost to "ineligible" site types would not be considered. Rangeland management specialists could be consulted to sort proposals into these site types, and to evaluate the potential impacts vs. benefits of compost application on each "evaluate" site.

NRCS is currently conducting field trials of rangeland compost application and is evaluating impacts on native plant diversity and C sequestration. As results from these trials become available and NRCS's Draft Conservation Practice Standard is revised accordingly and finalized, it may be possible to narrow the "evaluate" category and adjust the application rates.

Table 4. Proposed compost application rate for rangelands. The application rate is consistent with cropland application rates in Table 2, and the cumulative nitrogen availability is less than the threshold for impact on plant diversity suggested by our scientific literature review.

Compost Type	Moist Compost Application Rate (tons/acre)	Equivalent Dry Compost Application Rate (tons/acre)	Cumulative lbs available N/acre at 5 years post-application
Lower N (C:N > 11)	6 – 8	4.0 – 5.3	15.7 – 20.9

Table 5. Types of sites for rangeland compost application. Compost application is expected to have the least impact on native plant diversity at "priority" sites, may have an impact at "evaluate" sites, and is likely to impact native plant diversity at "ineligible" sites. Both "priority" and "evaluate" site types would be eligible for the incentives program.

Site Type	Examples
Priority	• sites that have been plowed, irrigated, heavily seeded, or otherwise disturbed such that the natural communities and soil conditions are no longer present • areas that have been depleted of their baseline soil organic matter through a variety of agronomic practices – resulting in areas such as degraded rangelands and/or abandoned agricultural lands that are generally considered to have poor soil health • retired agricultural lands that are being restored or converted to rangelands • other sites where soils have been previously tilled or subjected to major soil disturbance, e.g., failed homesteads • small holding/feeding pastures • fallowed fields
Evaluate	• any rangeland area not described under "Priority" or "Ineligible"
Ineligible	• slopes greater than 15% • seasonal wetlands such as vernal pool complexes (including surrounding uplands) • wet meadows or other seasonally inundated rangelands, regardless of slope (e.g., floodplains) • more permanent wetlands, including any area with hydric soils • sagebrush steppe • alkali sinks • desert grasslands* • native coastal prairies • serpentine and serpentine-influenced soil types • chaparral, coastal sage scrub, and other systems dominated by native shrubs • grasslands currently designated as mitigation and/or conservation lands • sites containing federal, state, and/or CNPS listed native plants; and/or animals that require low-stature rangelands for their life history, including but not limited to San Joaquin Kit Fox, Giant Kangaroo Rat, Tiger Salamander, and/or Burrowing Owl • sites that have recently burned** • sites in watersheds already impacted by N or P (i.e., listed under section 303d of the Clean Water Act for nutrient pollution), unless appropriate mitigating practices included

* Compost application on desert grassland sites where vegetation is dominated by invasive Eurasian grasses, such as cheatgrass (*Bromus tectorum*), may be considered as part of an overall restoration strategy, where grazing is present.

** Compost application as a strategy for rehabilitating select burned sites may be considered, where grazing is involved.

Summary of compost application rates for croplands and rangelands

A summary of the recommend rates for compost application to support a CDFA incentive program on soil health is provided in Table 6 below.

Table 6. Recommendations of the subcommittee for compost application to agricultural lands distributed by type of agricultural system, C:N ratio and type of farming. The rates to use for the proposed incentives program are the "equivalent dry compost application rates"(†), which should be converted to corresponding moist compost application rates on a batch-specific basis using moisture data from the compost facility.

System	Management	Crop Type	Compost Type	Moist Compost Application Rate (tons/acre)	Equivalent Dry Compost Application Rate (tons/acre)†
Cropland	Conventional	Annual	Higher N (C:N ≤ 11)	3 – 5	2.2 – 3.6
Cropland	Organic	Annual	Higher N (C:N ≤ 11)	3 – 5	2.2 – 3.6
Cropland	Conventional	Annual	Lower N (C:N > 11)	6 – 8	4.0 – 5.3
Cropland	Organic	Annual	Lower N (C:N > 11)	6 – 8	4.0 – 5.3
Cropland	Conventional	Tree	Higher N (C:N ≤ 11)	2 – 4	1.5 – 2.9
Cropland	Organic	Tree	Higher N (C:N ≤ 11)	2 – 4	1.5 – 2.9
Cropland	Conventional	Tree	Lower N (C:N > 11)	6 – 8	4.0 – 5.3
Cropland	Organic	Tree	Lower N (C:N > 11)	6 – 8	4.0 – 5.3
Rangeland	--	--	Lower N (C:N > 11)	6 – 8	4.0 – 5.3

Other Considerations

Nitrous oxide (N_2O) emissions. An additional issue that was raised was whether compost application to croplands could cause increases in nitrous oxide (N_2O) emissions, because additional organic carbon could potentially increase N_2O emission rates when soils are relatively saturated (> 80% water-filled pore space). However, under most other conditions, reactions related to nitrification including ammonia oxidation and nitrifier denitrification are believed to be the dominant contributor to N_2O emissions from California's agricultural soils[32,33]. These reactions are carried out by autotrophs that are not stimulated by organic carbon addition. N_2O production pathways tend to be stimulated by addition of ammonium, such that an increase in N_2O emissions may be noted when comparing compost-amended soil to an unamended control because of the ammonium provided by the compost. However, the impact of ammonium addition via compost would not be expected to be greater than that of addition of an equivalent amount of ammonium from any other nitrogen source.

Organically-managed croplands. There is considerable variation among organic growers in the use of compost for plant nutrient provision; some growers apply substantial compost to supply a significant percentage of crop nutrient needs, whereas others may apply little to no compost and rely on other organic nutrient sources, such as manure, certain cover crops, and feather meal[12]. At the second scientific subcommittee meeting, the application rates eligible for financial incentives was recommended to be the same for organic and conventional operations (Table 6), with the understanding that organic growers, in general, may apply greater amounts of compost in total.

Pathogens. Concern about the potential presence of pathogens in compost may make some growers hesitant to adopt compost application. However, the heat generated during the composting process kills the vast majority of pathogenic microbes, typically reducing them below detectable levels[34–36]. Furthermore, any pathogens that might remain are often outcompeted in the later stages of compost maturation, because the simple carbon compounds that are their preferred food source get consumed, leaving the more complex compounds - on which other microbial groups (such as fungi) are strongly favored - as the dominant food source[36,37]. Finally, in California, most compost that is sold - and all compost that could be applied in this incentives program - is subject to rigorous testing for any residual pathogens and must pass all such tests before it is cleared for sale (14 CCR Section 17868.3).

Monitoring. The desirability of collecting monitoring data in association with these compost applications on both croplands and rangelands was noted in public comments. Such data collection would be helpful to quantify both the benefits and potential environmental impacts of compost application and may allow future adjustment of application rates. For soils, standard physicochemical analysis including all plant nutrients and toxins, soil organic matter (SOM), and compaction and infiltration rates would be desirable and should be collected with a sampling design that appropriately captures site variability. On rangelands, additional plant data to collect would include percent bare ground, residual dry matter (RDM), species composition, vegetation production, and photo monitoring of representative sites where compost has been applied (along with paired control sites where it has not).

Life cycle concerns. A frequently-raised question is whether the CO_2 emitted in transporting compost to the rangeland site would be greater than the C sequestered as a result of its application. This might be the case if considering only the C sequestered via biological activity on site, which for rangelands is estimated to be approximately 50% of the CO_2 emitted during transport based on a life cycle analysis using data from these northern California rangeland sites[6]. However, this balance depends on the system to which compost is applied and the methods used to make emissions estimates. For example, a California Air Resources Board study of compost application to croplands estimated that transport to the application site would emit 0.008 MT CO_2e per ton of composted feedstock while on-site soil C increases (estimated using biogeochemical process modeling rather than field data) would sequester 0.26 MT CO_2e per ton of composted feedstock, on average[7]. Furthermore, if increased demand for compost created by rangeland application is assumed to be directly responsible for increased diversion of organic waste from landfills and/or manure from slurry ponds into aerobic composting processes, then this practice reduces GHGs due to avoided methane emissions[2] which is 28 times more potent than carbon dioxide. Assessing this claim is beyond the scope of this report, as there are numerous other drivers of diversion of organic wastes and manures to composting in California, such that it is difficult to estimate the present and potential future contributions of rangeland demand.

Rangeland site assessments. For rangelands, an in-person site assessment by a qualified professional, as stipulated in the American Carbon Registry Protocol[38], is highly recommended, as well as careful consideration of application rates in the context of site conditions. This professional should survey the site for species of conservation concern, identify any potential places where nutrient transport poses a eutrophication risk, recommend BMPs to mitigate runoff, and assess other resource concerns as appropriate. Comprehensively evaluating a practice's potential effects on all natural resources is a standard NRCS procedure, and, as such, should be part of any Compost Addition to Rangelands Conservation Practice Standard.

Technical assistance for program applicants. The Healthy Soils incentives program is proposed to be based on conservation practices developed by the USDA Natural Resources Conservation Service (NRCS). The application of Conservation Practice Standards is adapted as needed for each individual site by technical personnel. These visits enable the potential benefits and environmental impacts of each practice to be assessed in a more site-specific manner. Site assessments are an important component of an incentive program and CDFA should evaluate if such a process can be established. Producers who have compost application listed as a practice in an existing Carbon Farm Plan or equivalent conservation plan would be welcome to apply to the incentives program for cost-share (of the rates listed here). However, such a document would not be required for participation in the incentives program, unless a process can be established to make these planning services easily available to all California producers.

Primary potential environmental impacts of compost application to rangelands

1. Potential impacts on nitrate: For nitrate leaching, rangelands might intercept more of the available nitrogen released from compost than croplands due to a greater spatial and temporal extent of plant cover. However, no direct field measurements of nitrate leaching from compost-amended rangelands are available in the scientific literature. For the northern California sites, Ryals et al.[17] used the DAYCENT model to estimate nitrate leaching in their laboratory study. The DAYCENT estimate was approximately 8.9 lbs NO_3-N/acre/year for the first 10 years post-application, which equates to approximately 40% of the N released from the compost leaching out as nitrate over that period (89 lbs NO_3-N/acre of the estimated 222 lbs N/acre released). Leaching rates were considerably lower for simulations of C:N = 20 and C:N = 30 composts than they were for the C:N = 11 compost that was used in the field study. These estimates now urgently require field-validation and testing at other sites.

2. Potential impacts on plant diversity: California rangelands support over 400 plants of conservation concern[39,40] and a number of rangeland wildlife species, some of which are also imperiled, require specific plants and/or vegetation structure for their food and habitat[41–43]. Concerns about the impact of compost addition on plant diversity are grounded in a fairly large body of studies that have documented significant changes in plant community composition – and usually decreases in diversity – in response to synthetic N fertilizer addition[44]. In general,

adding N increases grass biomass more so than forb biomass, such that a few highly-responsive grass species (mostly non-native) can outcompete many of the forbs (mostly native)[45].

However, most of these studies have applied fairly high rates of N (80-100 lbs N/acre/year) in their experiments. There is a lack of scientific peer reviewed studies in California grasslands that have added a range of N rates to determine a threshold rate of N addition above which diversity is likely to decline. A few studies have attempted to determine N "critical loads" at which effects on the ecosystem are discernable[29–31,46]. These studies suggested that a critical load for California grasslands could be 6-9 lbs N/acre/year, but they are based on limited observational data along an N deposition gradient in serpentine grasslands. Because nutrient-poor serpentine grasslands may be more sensitive to nutrient addition than other California grassland types, more research is needed to evaluate whether this constitutes a basis for an application rate limit that would be relevant to most California rangelands.

3. Nutrient Run-off. For eutrophication concerns on rangelands, mandatory buffers around all surface waters combined with a site-specific risk factor analysis is an alternative strategy to across-the-board limits on application rates. Required buffer width for the incentives program will be 30 feet (at a minimum) around all surface waters on or adjacent to the parcel. For the risk factor analysis, similar to the "phosphorus index" approach applied in many states to evaluate risk from phosphorus application to croplands[47], rangeland areas with low soil N and/or P that are at a considerable distance from waterways probably would not create significant risk and therefore might base their application rates on other concerns. For areas that do have one or both of these risk factors, a more detailed risk assessment can be conducted[47], and some or all of the risk could be mitigated by adjusting the compost application rate and/or using best management practices (BMPs) in addition to the required buffers. Alternatively, potentially problematic areas of the property could simply be avoided if there are other more suitable areas. The American Carbon Registry's Methodology for Compost Additions to Grazed Grasslands[38] recommends a site survey by a Qualified Expert (i.e., a Certified Rangeland Manager, NRCS Soil Conservationist or Qualified Extension Agent) before compost is applied to assess this and other risks. In relation to these nutrient run-off concerns, some compost experts also noted that compost use in soil erosion prevention and degraded site mitigation is documented at rates much higher than those proposed here.[48,49]

Additional considerations for rangelands. Because addition of compost to rangelands may increase biomass production[4], which could increase fire risk in addition to potential plant diversity impacts, application of compost to *grazed* rangelands only is recommended. Application to ungrazed sites would only be advisable if part of a degraded rangeland restoration project, guided by an appropriate conservation or restoration plan.

Five of the nine studies in the literature review presented here involved non-composted organic amendments. Nitrogen mineralization is likely to be faster in non-composted than in composted amendments, such that levels of available N may be underestimated for non-composted amendments in Table 3.

Nitrogen is not the only soil nutrient that could increase with compost addition, as compost usually contains significant phosphorus, potassium, and other secondary plant nutrients as well. Here, rates were determined based on N release because there are more studies demonstrating N impacts on California grassland plant communities than there are for other nutrients [44]. However, other nutrients and indirect effects may have important consequences over the longer term[50].

It is important to consider the ecology of California rangeland plant communities when evaluating findings of "no impact" on their diversity. Many rangeland forb species form seed banks and only appear in years that are favorable for them. Any change in soil conditions may alter the degree of favorability of such years for these species, but this alteration may not be detected within the timeframe of most published studies. These dynamics suggest a precautionary approach to practices that could impact California rangeland plant diversity.

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