Methods to Assess Co-Benefits of California Climate Investments

Soil Health and Conservation

Center for Resource Efficient Communities, UC-Berkeley
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I. Background

Under California's Cap-and-Trade program, the State's portion of the proceeds from Cap-and-Trade auctions is deposited in the Greenhouse Gas Reduction Fund (GGRF). The Legislature and Governor enact budget appropriations from the GGRF for State agencies to invest in projects that help achieve the State's climate goals. These investments are collectively called California Climate Investments (CCI).

Senate Bill 862 requires the California Air Resources Board (CARB) to develop guidance on reporting and quantification methods for all State agencies that receive appropriations from the GGRF. Guidance includes developing quantification methodologies for greenhouse gas (GHG) emission reductions and other social, economic, and environmental benefits of projects, referred to as "co-benefits."

This document is one of a series that reviews the available methodologies for assessing selected co-benefits for CCI projects at two phases: estimating potential project-level co-benefits prior to project implementation (i.e., forecasting of co-benefits), and measuring actual co-benefits after projects have been implemented (i.e. tracking of co-benefits). The assessment methodology at each of these phases may be either quantitative or qualitative. As with CARB's existing GHG reduction methodologies, these co-benefit assessment methods will be developed to meet the following standards:

- Apply at the project level
- Align with the project types proposed for funding for each program
- Provide uniform methods to be applied statewide, and be accessible by all applicants
- Use existing and proven tools or methods where available
- Use project level data, where available and appropriate
- Reflect empirical literature

CARB, in consultation with the state agencies and departments that administer CCI, has selected ten co-benefits to undergo methodology assessment and development. This document reviews available empirical literature on the ***soil health and conservation*** co-benefit and identifies:

- the direction and magnitude of the co-benefit,
- the limitations of existing empirical literature,

- the existing assessment methods and tools,
- knowledge gaps and other issues to consider in developing co-benefit assessment methods
- a proposed assessment method for further development, and
- an estimation of the level of effort and delivery schedule for a fully developed method

II. Co-benefit description

California's soils are the underpinning of the state's $20 billion agricultural economy, including both cultivated (cropland) and non-cultivated (rangeland and pasture) lands. Soils also play a critical role in the health of natural lands including forests, wetlands, grasslands, watersheds, and species habitats throughout the state. Healthy soils can also play a key role in mitigating greenhouse gas emissions, through carbon sequestration. Soils are threatened by nutrient depletion, salination, wind and water erosion, subsidence, and loss of organic matter and biodiversity, resulting from over-use**,** chemical soil contamination, and conversion to urban uses. This can result in significant soil loss, and a reduction or elimination of soil productivity for agricultural, silvicultural, or ecological purposes.

Soil conservation refers to the prevention of soil loss and degradation from water and wind erosion, typically resulting from urbanization, deforestation, overgrazing, and intensive agricultural cultivation. Soil conservation also refers to the restoration of soil productivity and health.

Soil health is a complex agglomeration of physical, chemical and biological factors that contribute to a given soil's capacity to function in:

- Sustaining biological diversity, activity and productivity (including agricultural productivity)
- Regulating water and solute flow
- Filtering, buffering, and degrading organic and inorganic materials
- Storing and cycling nutrients and carbon
- Providing physical stability and support (NRCS 2015)

These critical functions are generally assessed through the measurement of key indicators including available water capacity, bulk density, infiltration capacity, electrical conductivity, pH, soil organic matter, total organic carbon, erosion, alkalinity, acidity, and several others.

Soil organic matter is an indicator that can serve as a good proxy for overall soil heath. It is "the fraction of the soil that consists of plant or animal tissue in various stages of breakdown" (Cornell Cooperative Extension 2008), generally between three and six percent in many productive agricultural soils elsewhere in the United States, but well below two percent in most of the agricultural areas of California (NRCS 2008). Soil organic matter contributes to all the soil functions listed above and provides numerous key benefits, including:

- Enhancing soil stability
- Enhancing soil aeration
- Improving water infiltration and water holding capacity (both of which reduce runoff)
- Reducing soil compaction and surface crusting
- Accelerating decomposition of soil minerals and liberating nutrients for plant uptake
- Enhancing soil microbial biodiversity and providing food for living organisms in the soil
- Enhancing the ability of a soil to resist pH change (Cornell Cooperative Extension 2008)

The California Healthy Soils Action Plan identifies the State's strategies to increase the organic matter of soils by:

- expanding the use of compost, biosolids, and other soil amendments that increase the carbon content of soils;
- balancing the addition of synthetic inputs with soil carbon and soil organic matter buildup;
- increasing water holding capacity of soils;
- increasing use of cover crops and managed grazing;
- permitting new composting and anaerobic digestion facilities; and
- supporting farmland conservation.

Soil conservation, particularly of productive agricultural soils, is also a policy objective of the state of California. The Farmland Mapping and Monitoring Project of the CA Department of Conservation tracks farmland conversion trends through its statewide classification of agricultural soils (see section VI below). In the most recent available data, from 2010 to 2012, the state lost over 70,000 acres of "important" farmland,[1] despite the national economic recession and lull in housing construction that characterized those years. Prior recent reporting periods from 2004-06, 2006-08, and 2008-10 showed higher rates of loss ranging from about 100,000 to 125,000 acres per bi-year (DOC 2017a). Most of this loss is due to expansion of urban areas and construction of new buildings and infrastructure on previously undeveloped lands in the near vicinity of existing cities, towns, and highways.

CCI can help support these, and other soil health and soil conservation objectives. Certain CCI have the co-benefit of improving soil health directly by sponsoring projects that increase organic matter content of soils, increase plant diversity on soils, manage soils by disturbing them less, or use cover crops and rotation. Some CCI impact soil

[1] Defined as the categories of Prime Farmland, Farmland of Statewide Importance, Unique Farmland, and Farmland of Local Importance

health indirectly as a by-product of the project’s primary goal, such as the production of compost. Other CCI have the co-benefit of soil conservation through reforestation, urban greening, easements, and/or restoration of cropland, rangeland, wetland, grassland, watershed, or forest soils. The “soil health and conservation” co-benefit therefore applies to any situation where a CCI project applicant is able to demonstrate that the project will improve soil health in, and/or conserve or restore agricultural (cropland, rangeland, and pasture land) and natural (forest, grassland, watershed or wetland) soils by: a) increasing soil organic content, b) producing compost or other soil amendments, c) restoring or converting land in a manner consistent with healthy soils, or d) conserving land with productive and healthy soils that might otherwise be developed or disturbed.

Conversely, there may be situations in which a CCI-funded project has a negative effect on this co-benefit if, for example, construction of new rails, facilities, housing, or buildings is carried out on agricultural or natural soils and results in soil disturbance and a change in land use classification. These construction projects can also potentially cause depletion of soil health from erosion or chemical contamination. Additionally, some forest projects can deplete soil health if they entail deep ripping.

Table 1 illustrates the Fiscal Year 2016-17 GGRF-affiliated programs for which one or more of these soil benefits (or dis-benefits) are most likely to accrue.

***Table 1**: CCI Programs Affected by Co-Benefit*

Program	Project	Likely direction of co-benefit (+ = beneficial change)
Sustainable Communities and Clean Transportation		
HSRA	High Speed Rail	-
CalSTA	Transit and Intercity Rail Capital Program (TIRCP)	-
Caltrans	Low Carbon Transit Operations (LCTOP)	-
SGC	Affordable Housing and Sustainable Communities (AHSC)	-
SGC	Sustainable Agricultural Lands Conservation Program (SALC)	+
SGC	Transformative Climate Communities (TCC)	+/-
Energy Efficiency and Clean Energy		
CDFA	State Water Efficiency and Enhancement Program (SWEEP)	+
Natural Resources and Waste Diversion		
CNRA	Urban Greening Program	+
DFW	Wetlands and Watershed Restoration	+
CDFA	Dairy Digesters and Research Development Program (DDRDP)	+
CDFA	Alternative Manure Management Practices (AMMP)	+
CDFA	Healthy Soils Program	+
CAL FIRE	Forest Health Program	+/-
CAL FIRE	Urban and Community Forestry (UCF)	-
CalRecycle	Waste Diversion	+

III. Directionality of the co-benefits

Many of the CCI programs listed above (primarily in the Energy Efficiency and Clean Energy, and Natural Resources and Waste Diversion sectors) fund projects that either directly enhance soil quality, produce compost or other soil amendments, or conserve or restore agricultural, silvicultural, and wetlands. In all such cases, these efforts will produce benefits for soil health and conservation, ***a positive co-benefit***.

CCI programs (primarily in the Sustainable Communities and Clean Transportation sector) that include the construction of new transit lines, facilities, housing, or buildings upon productive soils, as well as forest projects that entail deep ripping, may result in ***negative co-benefits***.

Some programs may have both positive and negative co-benefits, such as the Transformative Climate Communities (TCC) program, which could entail both transportation and urban greening projects.

IV. Magnitude of the co-benefit

Overall, soil health and conservation co-benefits are likely to be significant when considered across the entire CCI portfolio because five CCI programs invest in projects specifically devoted to soil health and/or conservation, and several others have indirect positive effects. Potential negative effects from expanded transportation and housing projects are not likely to be large enough to outweigh the positive co-benefits across the entire CCI portfolio.

There is substantial research on the magnitude of soil health benefits from practices that increase soil organic matter. A large body of research has examined the effect of altering tillage practices, rotating crops, and restoring degraded soils (e.g. Varvel and Wilhelm 2010, Akala and Lal 2001). However, a growing literature assesses the effects of application of compost, biosolids and other organic residuals, not only on croplands but also on range and grasslands. Additions of organic wastes such as anaerobic sludge, cattle manure, and municipal compost have consistently been shown to decrease bulk density and increase waterholding capacity of soils, as well as increase carbon storage capacity (Khaleel et al 1981, Albaladejo et al 2008, Lindsay and Logan 1998).

Brown and Cotton (2011) conducted a field survey to quantify the benefits of applying compost to agricultural soils on seven farms around California (in Riverside, Ventura, Kern, Kings, Stanislaus, and Monterey counties). They found that compost application tripled soil organic carbon in comparison to control soils, increased soil microbial activity by 2.23 times that of control soils, and reduced bulk density to 0.87 times that of control soils. Nutrient availability in the composted soils was comparable to conventionally managed soils (i.e. those that receive chemical fertilizers), and water infiltration times were significantly reduced. While infiltration was most improved in finer textured soils, the largest improvements in water holding capacity were found in coarser soils, matching previous results from Rawls et al (2003) and Bauer and Black (1992).

Brown et al (2011) also found that application of 50 Mg/ha of compost to orchard lands in Washington State would result in 12 Mg of increased soil carbon, 0.80 Mg of increased nitrogen, and 0.20 Mg of increased phosphorus per hectare, and that water use would be reduced by 1000 m^3/ha. Ryals et al (2014) found that a single, 1.3 cm-thick (0.5 in) application of composted green waste resulted in increases in soil carbon and nitrogen levels of 26 and 54 percent, respectively, at an inland California grassland site, and 37 and 53 percent, respectively, at a coastal California grassland site.

Another body of literature focuses on the magnitude of soil conservation benefits from agricultural practices that control and mitigate soil erosion. These practices typically entail maintaining a protective vegetative soil cover (soil organic matter, mulch, cover crops), reduced tillage, and/or agroforestry, all of which also improve soil health (Pimentel et al 1995). Grismer and Hogan (2005b) found that mulch reduced soil erosion from bare slopes in the California Tahoe Basin by an order of magnitude. Studies have also shown that plants can play an essential role in stabilizing soil, although they do not always limit erosion to acceptable levels (Elliot 2002; Zhang 2002).

Conservation and easement projects can have positive soil conservation benefits when they implement soil health practices, or when they prevent conversion of land to other uses that would degrade soils.

i. Project Type 1: Agricultural Soil Health Activities

Several programs identify agricultural **soil health** as a central purpose of funded projects, and will produce significant co-benefits at both the project and program scale. CDFA Healthy Soils projects will directly improve soil health on agricultural lands through the application of compost and biosolids, mulch, or cover crops, as well as other soil management practices such as crop rotation and reduced tillage. The Alternative Manure Management Practices (AMMP) program is also likely to produce direct positive soil health impacts on grasslands and rangelands, as conversion to pasture is a strongly advocated practice. The State Water Efficiency and Enhancement Program (SWEEP) gives a competitive advantage to projects that implement healthy soil management practices that increase water-holding capacity. Finally, a core objective of the Wetlands and Watershed Restoration program is carbon sequestration through increased soil carbon.

ii. Project Type 2: Conservation Easements

Some CCI projects directly conserve soils within their project areas though conservation easements. The Sustainable Agricultural Lands Conservation (SALC) program impacts soil conservation directly as a primary objective, through agricultural land mitigation, conservation easements, and increased zoning minimums for agricultural areas. The CAL FIRE Forest Health program also impacts soil health directly by funding projects that conserve forestland by avoiding conversion to other uses. These projects could have significant soil conservation co-benefits by preventing land conversion of forest or agricultural soils designated as FMMP Prime or Unique farmland, or Farmland of Statewide or Local Importance. These co-benefits will be significant at both the project and program levels.

iii. Project Type 3: Production of Soil Amendments

Other CCI programs fund projects that impact soil health indirectly by producing compost and other soil amendments as a by-product of their projects' primary purposes. The CDFA Dairy Digester and Research Development Program (DDRDP) funds projects that use anaerobic digestion to produce fertilizer and other soil amendments. The CDFA Alternative Manure Management Practices (AMMP) and CalRecycle Waste Diversion program both include compost production as a project product.

iv. Project Type 4: Land Use Conversion

Programs that entail land use conversion could have either a positive or negative impact on soil health and conservation. Projects in the Sustainable Communities and Clean Transportation sector could have significant negative effects on soil conservation at the project level if new transit facilities, rails, housing, and buildings are sited on agricultural or natural lands, and if offset activities are not undertaken. Relevant programs include the High Speed Rail (HSR) program, the CalSTA Transit and Intercity Rail Capital Program (TIRCP), the Caltrans Low Carbon Transit Operations Program (LCTOP), and the SGC Affordable Housing and Sustainable Communities (AHSC) and Transformative Climate Communities (TCC) programs. The negative co-benefits of these programs may be significant at the program level, depending upon the proportion of projects that are located on previously undeveloped sites or agricultural lands outside of existing urban areas.

However, these programs may carry out mitigation efforts to offset the negative soil health and conservation impacts from land use conversion, thus changing the net directionality of the co-benefit impact. For example, the HSR program implements acre for acre conservation easements for all consumed land to offset impacts, and this will likely have a positive soil health benefit (California High Speed Rail, 2016). These easements include agricultural conservation easements funded by the Department of Conservation’s California Farmland Conservancy Program (CFCP), and wetland conservation easements to preserve wildlife habitat. HSR will also invest in urban tree planting to offset GHG emissions, which may have a positive impact on soil health.

On the other hand, projects that convert urban parcels or other developed sites to natural or agricultural lands could have a positive impact on the soil conservation co-benefit, although the magnitude of the benefit may not be significant. Conversion projects in urban area, such as those funded by the CNRA Urban Greening program and the CAL FIRE Urban and Community Forestry (UCF) program are not likely to have significant soil health and conservation co-benefits at either the project or program levels. Though conversion of urban parcels to vegetated open spaces likely represents a revival of the soil body’s biological productivity, it may also increase soil’s vulnerability to erosion through the exposure of soils during the re-vegetation process, and through exposure to high pedestrian traffic, recreational use and rainfall. Individual projects that specifically involve soil health enhancement practices such as application of organic matter amendments may form an exception (such as those that fund conversion to pasture in the CDFA Alternative Manure Management Practices program), but these are unlikely to be numerous enough to make co-benefits significant at a program level.

v. Project Type 5: Restoration or Greening Activities

Some CCI projects may conserve and improve soil health within their project areas as a by-product of restoration or greening activities. Projects funded by the Forest Health, Urban and Community Forestry (UCF), and Wetlands and Watershed Restoration programs are primarily focused on tree or vegetation planting and management, forest thinning, and related activities. In cases where these projects create wholesale transformation of a watershed's vegetative land cover (e.g. by re-planting denuded landscapes with trees), significant immediate soil conservation co-benefits would accrue at the project level. The soil health and conservation co-benefits from projects that thin forests, re-plant small portions of watersheds, plant trees on small plots in urban areas, or change the management of existing vegetative cover are unlikely to produce significant short-term co-benefits that are quantifiable by currently available methods. However, forestry projects in particular may have significant long-term impacts on reducing mortality, conversion, and/or wildfire, thus leading to positive soil health and conservation co-benefits. Thus, it is uncertain whether soil health and conservation benefits will be significant at the program level for these CCI programs.

V. Limitations of current studies

For the purposes of co-benefit assessment, the most important limitation of the existing literature is the lack of single quantified metric to characterize soil health. Soil organic matter (SOM) is often an adequate proxy, although it is limited. Most studies of soil health report results across several different metrics, each of which can significantly affect crop yields, soil biodiversity, or other indicators of a healthy soil. In fact, because soil health is multi-dimensional, the outputs of some synthesis methods for assessing soils (such as the Storie Index or the Cornell Soil Health Assessment described in section VI below) focus more on the factor that may be placing the tightest limitations on the soil's productivity, rather than on the factors that enhance it the most.

Related to this is the fact that soil health is not easily characterized in detail without field-based or even laboratory-based tests. Key parameters such as water-holding capacity and electroconductivity are not observable through informal means or through mass data collection like remote sensing. The diversity of soil conditions, hydrological conditions and past uses defies easy generalizations about the likely ranges of key soil parameters in particular locations. It can also limit the transferability of specific findings from other geographical contexts, since the limiting factors on productivity may be different in other places.

VI. Existing quantification methods/tools

This co-benefit involves two different assessment needs – assessing soil health and soil conservation – for which the following methods and tools may be useful.

i. Methods for assessment of soil health

Because soil health involves many factors and variables, most assessment methods involve classification or rating schemes that aggregate many factors into a few major classes or categories of quality. Many of the CCI program benefits listed above directly affect the criteria that are used to classify and rank the quality of soils.

a. NRCS Land Capability Classification

A basic and widespread such scheme is the USDA Natural Resource Conservation Service (NRCS) Land Capability Classification, in use since 1961 and the basis of NRCS soil surveys throughout the United States. This system groups soils into eight basic classes, ranging from Class I (soils that have “slight limitations that restrict their use”) to Class VIII (soils that have “limitations that preclude their use for commercial plant production”). Each soil body is further defined with a subclass that identifies the source of the potential use limitations:

- Subclass e: Erosion susceptibility or past erosion damage
- Subclass w: Excess water, including poor soil drainage or a high water table
- Subclass s: Rooting zone limitations including low fertility, shallowness of rooting zone, stones, low moisture-holding capacity, and salinity
- Subclass c: Adverse climate, including temperature or lack of moisture

The basic land capability classes are defined through qualitative distinctions, such as the following example:

“Limitations of soils in Class II may include singly or in combination the effects of (1) gentle slopes, (2) moderate susceptibility to wind or water erosion or moderate adverse effects of past erosion, (3) less than ideal soil depth, (4) somewhat unfavorable soil structure and workability, (5) slight or moderate salinity or sodium easily corrected but likely to recur, (6) occasional damaging overflow, (7) wetness correctable by drainage but existing permanently as a moderate limitation, and (8) slight climatic limitations on soil use and management.” (USDA 1961)

Only subclasses w and s bear any direct relationship to soil organic matter levels, and only when the respective issues are entirely removed as limitations would a given soil body exit one subclass and enter another. Furthermore, the subclasses are prioritized in the order presented above, so that a soil limited by both erosion and excess water, for example, would be placed in subclass e as opposed to subclass w. Improvements to fertility or soil drainage brought about through soil amendments, therefore, may not alter the subclass in which a given soil body is placed if “higher-ranking” limitations are also present.

b. Storie Index Soil Rating

The Storie Index Soil Rating (Storie 1978) is a widely used method, developed in California, for rating the quality of agricultural soils based upon the "soil characteristics that govern the land's potential utilization and productive capacity." It is derived from four factors:

- Factor A: Physical profile (e.g. recent alluvial fans, upland areas underlain by bedrock, etc.)
- Factor B: Surface texture (e.g. fine sandy loam, silty clay, coarse sand, etc.)
- Factor C: Slope (e.g. nearly level, gently undulating, moderately sloping, etc.)
- Factor X: Other conditions: drainage, alkalinity, nutrient levels, acidity, erosion, and microrelief

Each factor is expressed on a scale from zero to 100 percent, the four factors are multiplied together to calculate the overall Storie Rating, and then classed into one of six grades on the basis of their final percentage rating. Grade 1 soils, for example, are those that "rate between 80 and 100 percent and which are suitable for a wide range of crops, including alfalfa, orchard, truck, and field crops," whereas Grade 6 soils are those that rate below 10 percent and are generally not suitable for agricultural uses.

Factors A, B, and C reflect fundamental characteristics of soils and are not affected by management actions or soil amendments. Of the six components of Factor X, only nutrient levels are directly affected by organic matter amendments, though the others could be indirectly affected. In the Storie Rating system, nutrient levels are only broadly categorized as high (100%), fair (80-100%), poor (80-95%), or very poor (60-80%). Other Factor X components are characterized similarly. These percentages are multiplied together with the Factor A-C scores only if one or more Factor X components is relevant as a downward modifier on the overall soil quality. Otherwise, all Factor X components are assumed to be 100%.

c. Revised Storie Index

A Revised Storie Index has been developed (O'Geen et al 2008) that more specifically defines the Factor X components. The "soil chemical and fertility limitations" portion of Factor X is quantified as pH, electrical conductivity, and sodium adsorption ratio, with only the most limiting of these three affecting the final rating calculation for any given soil. These three factors have a less direct relationship to organic matter levels than the previous characterization of nutrient levels, and because only the most limiting of the three is used in the calculations, there may be many situations in which increasing organic matter levels in a given soil body would not appreciably change the final Revised Storie rating.

d. Storie Rating for Timber Sites

There is also a Storie Rating for Timber Sites (Storie and Wieslander 1948), which multiplies together five factors: depth, permeability, chemical (alkalinity, salinity, etc), drainage, and climate. Of these factors, only permeability and drainage are likely to be substantially affected by organic matter amendments or forest management practices, and each are characterized in very coarse categories (e.g. permeable profiles, slowly permeable profiles; well drained, imperfect drainage, poor drainage) that will not be sensitive to the changes introduced by any soil amendments, particularly when considered over land areas relevant to forest management.

e. Farmland Mapping and Monitoring Project (FMMP) Classification

The California Department of Conservation's Farmland Mapping and Monitoring Project (FMMP) adapted the USDA's nationwide Land Inventory and Monitoring classifications of farmland to California conditions. This system maps land into one of eight classifications (DOC 2017b):

- Prime Farmland
- Farmland of Statewide Importance
- Unique Farmland
- Farmland of Local Importance
- Grazing Land
- Urban and Built-Up Land
- Other Land
- Land Committed to Non-Agricultural Use

Prime Farmland and Farmland of Statewide Importance are defined in terms of quantified thresholds for various soil quality criteria, including water, soil temperature, acid-alkali balance, water table, soil sodium content, flooding, erodibility, permeability, rock fragment content, and rooting depth. Increasing soil organic matter directly enhances at least five of these ten criteria. Other land classifications are not quantified in this manner, however, and most public land areas, such as national forests and Bureau of Land Management holdings, are not mapped. These factors limit the system's potential use as a means of assessing soil health improvements from amendments and other management techniques, as well as conversion of non-agricultural natural lands (such as forests, wetlands, grasslands, and watersheds). However, because the FMMP has mapped agricultural and private land for the entire state of California[2], the system is widely used to report on farmland conservation activities.

[2] http://www.conservation.ca.gov/dlrp/fmmp/Pages/county_info.aspx

f. NRCS Soil Health Card

Another tool for assessing soil quality is the NRCS Soil Health Card (NRCS 2001). Designed for use by farmers, the cards contain a series of soil health indicators that the user ranks as low, medium or high according to short qualitative descriptions of the conditions. For example, for the indicator "water holding capacity," the three descriptive options are "plant stress immediately following rain or irrigation, soil has limited capacity to hold water, soil requires frequent irrigation" (low), "crops are not first to suffer in area from dry spell, soil requires average irrigation" (medium), and "soil holds water well for long time, deep topsoil for water storage, crops do well in dry spells, soil requires less than average irrigation" (high). There is no indicator that directly assesses soil organic matter, though several indicators (earthworms, soil organisms, surface organic material, workability, soil tilth, porosity, water infiltration, water holding capacity, and crop vigor) are affected by soil organic matter levels. Each indicator is assessed independently and there is no procedure by which to sum up individual indicator assessments to an overall soil health rating. Many states have developed customized soil health cards based on the NRCS template to reflect local conditions and farmer preferences, but California has not.

g. Cornell Soil Health Assessment

Among available on-farm and laboratory-based soil testing procedures, the Cornell Soil Health Assessment (Moebius-Clune et al 2016) provides interpretive guidance on soil health indicators that could be adapted into a generalized assessment tool for prospective soil health project investments. Unlike the USDA's Soil Quality Test Kit[3], the Cornell assessment also directly measures soil organic matter content (among other parameters) and provides direct interpretive guidance to the consumers of the test results. Farmers must mail soil samples to a laboratory to obtain results. Figure 1 relates the percentage of soil organic matter in a soil sample to a 1-100 score that is then classed into five bands indicating overall quality. These five quality bands recur in similar graphs for other soil health parameters (see Figure 2), enabling all to be compared along a common scale.

[3] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=nrcs142p2_053873

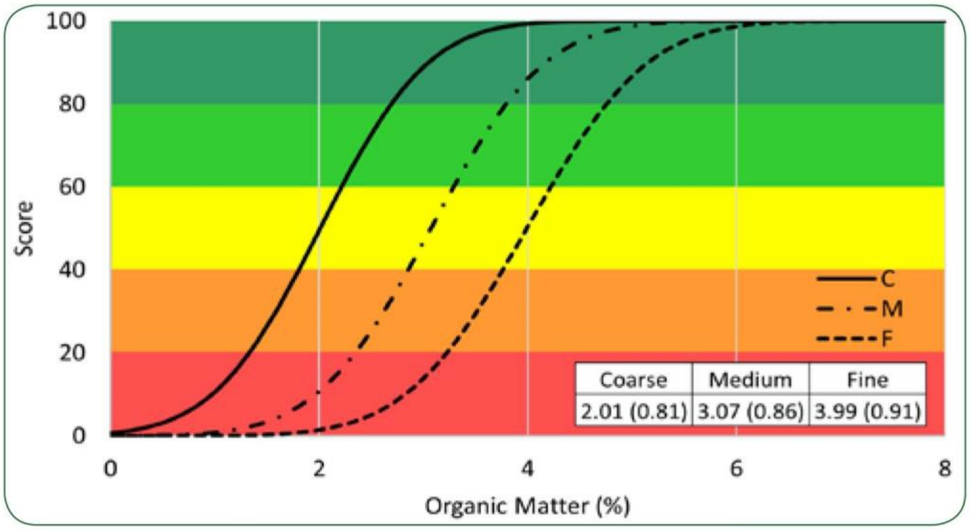

Figure 1. Soil Organic Matter scoring functions and upper value limits for Coarse (C), Medium (M), and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided in the box at lower right. From Moebius-Clune et al (2016).

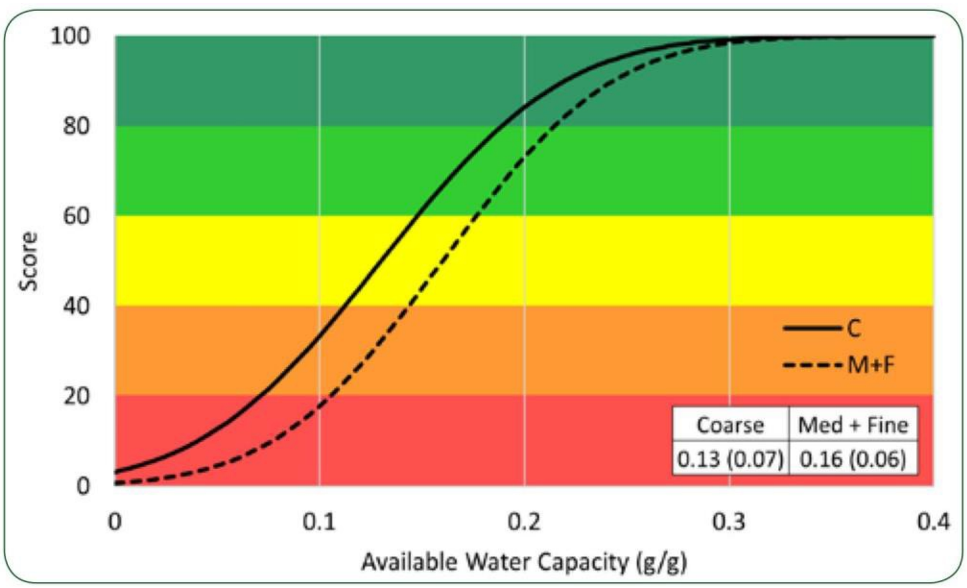

Figure 2. Available Water Capacity scoring functions and upper value limits for Coarse (C), Medium (M), and Fine (F) textural classes. Mean and standard deviation (in parenthesis) for each class are provided in the box at lower right. From Moebius-Clune et al (2016).

h. Gravuer Method of Compost Application Rates

Another possible assessment method specifically for projects with organic matter amendments is to compare planned applications of organic matter, or the capacity for such applications, to the application rates recommended to achieve meaningful soil health improvements. For instance, recommended compost application rates were developed by a subcommittee convened by the CA Department of Food and Agriculture (CDFA) to support development of a GHG quantification method for the Healthy Soils program. These recommended application rates were set at levels that, in the opinion of the experts on the subcommittee, would ensure achievement of the many soil health benefits associated with organic matter soil amendments while minimizing potential for negative environmental impacts from excessive application, such as nitrate leaching to groundwater (Gravuer 2016). As Table 1 shows, these ideal rates vary by crop type, conventional vs. organic management, and compost type, but range between two and eight tons per acre.

System	Management	Crop Type	Compost Type	Moist Compost Application Rate (tons/acre)	Equivalent Dry Compost Application Rate (tons/acre)t
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

Table 1. Recommended compost application rates to California agricultural lands by type of agricultural system, C:N ratio, and type of farming. From Gravuer (2016).

ii. Methods for assessment of soil conservation

a. Land Evaluation and Site Assessment (LESA) model

A widespread method of potential use in assessing the quality of agricultural soil conversion or conservation projects is the Land Evaluation and Site Assessment (LESA) model, developed by the CA Department of Conservation to adapt previous federal LESA models to California conditions. The LESA model (DOC 1997) creates a 0-100 score that indicates the potential significance of a project’s conversion of agricultural lands for purposes of evaluation under the California Environmental Quality Act (CEQA). The LESA score is calculated as shown in Figure 3 below.

A	B		C		D
Factor Name	Factor Rating (0-100 points)	X	Factor Weighting (Total = 1.00)	=	Weighted Factor Rating
Land Evaluation					
1. Land Capability Classification	<Line 1>_______	X	0.25	=	_______
2. Storie Index Rating	<Line 2>_______	X	0.25	=	_______
Site Assessment					
1. Project Size	<Line 3>_______	X	0.15	=	_______
2. Water Resource Availability	<Line 4>_______	X	0.15	=	_______
3. Surrounding Agricultural Lands	<Line 5>_______	X	0.15	=	_______
4. Protected Resource Lands	<Line 6>_______	X	0.05	=	_______
			Total LESA Score (sum of weighted factor ratings)		<Line 7>_______

Figure 3. Final LESA scoresheet showing the components of the final score and the weighting assigned to each component. From DOC (1997).

The Land Capability Classification factor rating is the area-weighted average of 0-100 scores reflecting the Land Capability Classifications of each of the soil types present in the site, and the Storie Index Rating factor score is the area-weighted average of the Storie Index for those same soils. The factor ratings for project size, water resource availability, the quality of surrounding agricultural soils, and presence of adjacent protected resource lands are expressed as 0-100 scores derived from calculations and lookup tables described within the LESA guidance manual. The higher the final LESA score, the more valuable the soil resource at risk (and hence the more significant the potential conservation of those soils by a project dedicated to that purpose).

b. InVEST model

It is also possible to estimate the sedimentation (i.e. soil erosion) rates from a farmed or forested watershed using the InVEST model, a free, open-source modeling suite developed by the Natural Capital Project at Stanford University (Sharp 2016). The InVEST sediment yield model works by breaking a watershed into grid cells, estimating the sediment yield from each grid cell based upon the Universal Soil Loss Equation (USLE), and then calculating a Sediment Delivery Ratio and Sediment Delivery Index based on other biophysical characteristics of the watersheds. The USLE was originally derived from studies of agricultural lands in the Midwest and does not capture all forms of erosion that may be important in California watersheds, especially in mountainous areas. Moreover, the USLE (and by extension the InVEST model) relies upon broad characterization of the vegetative cover of a given watershed (e.g. forest, grassland) and therefore is not sensitive to management-induced changes of vegetation density within those classifications.

VII. Knowledge gaps and other issues to consider in developing co-benefit quantification methods

i. Applicability of methods across different land classifications and practices

Many of the above quantification methods are limited to specific land classifications or practices, limiting applicability across programs. Some methods of estimating land use conversion, such as the Farmland Mapping and Monitoring Project (FMMP) Classification and the Land Evaluation and Site Assessment (LESA) model are limited to agricultural vs. non-agricultural land, limiting applicability for programs that impact other land types (such as forests, wetlands, grasslands, and watersheds). However, these models should suffice for a majority of projects in the Sustainable Communities and Clean Transportation sector that entail land use change or conversion, as they will most commonly occur on either croplands or rangelands adjacent to urban areas.

ii. Logistical difficulty of field- and laboratory-based soil tests

As noted in the limitations section, a majority of quantification methods listed above for assessing soil health require field-based or even laboratory-based tests, which would create a substantial reporting burden for CCI applicants. This includes the Storie Index Soil Rating and revised indices, and the Cornell Soil Health Assessment. The NRCS Soil Health Card does not require soil testing, but this tool has not been adapted for California. Other methods rely on map-based land classifications, but do not measure soil health directly.

iii. Practice duration

Another consideration for assessing a project's magnitude of impact on soil health and/or conservation is the duration of time a practice is implemented, and the lag between implementation and observable changes in soil health, which may be many years. Some practices, such as land use conversion, are generally implemented over many years and take even longer to accrue the full benefits of soil health. Others, such as compost application, may only happen in a few instances but have relatively immediate impacts on soil health.

iv. Permanence

Permanence refers to the level of certainty that the benefits of soil health practices will persist over time and not be reversed. Holding practice duration equal, some agricultural practices, such as easements or planting trees, have greater levels of permanence than others, such as reducing tillage. A subsequent change in practices may result in the reversal of these benefits.

VIII. Proposed method/tool for use or further development, schedule, and applicant data needs

Given these findings, we offer the following recommendations for methods and tools to assess soil health and conservation co-benefits, schedule for development of guidance documents, and applicant data needs.

Overall, the methodology for estimating the soil health and conservation co-benefit should be qualitative for both direct and indirect impacts, amounting to prediction and monitoring of the number of acres of soil to be impacted by the project or practice.

Projects that impact agricultural soil health directly through activities such as cropland management or application of soil amendments should predict and report on the number of acres to be impacted by each practice (e.g. number of acres to receive compost applications, or implement crop rotation). This methodology rests on the assumption that any acreage that implements a practice will result in improved soil health. While quantitative indicators of soil health that have greater scientific certainty would be ideal, we recommend that these be optional, as they require field-based or laboratory-based soil tests, which would create a substantial reporting burden. However, if the project applicant is already required to conduct soil tests to estimate soil carbon sequestration for CCI reporting, they should additionally report quantitative metrics of soil health improvement using the Cornell Soil Health Assessment (as described below).

Projects that produce compost and other soil amendments should estimate the number of acres of soil to be potentially indirectly improved. Projects that have negative impacts on soil conservation through urbanization should predict and monitor the quantity of acreage that will undergo a conversion of land classification.

Projects that impact agricultural soil conservation through easements or land conversion should estimate the number of acres of high-quality soil conserved, as defined by the Farmland Mapping and Monitoring Project land classifications.

Projects that include restoration or greening activities should only optionally report indicators already required for the funding program, due to the uncertainty around quantification and magnitude of the co-benefit (so as to minimize the reporting burden).

i. Methods for estimation prior to award of CCI funds:

a. Project Type 1: Agricultural Soil Health Activities

CDFA Healthy Soils Program; State Water Efficiency and Enhancement Program (SWEEP):

Estimation of acres of soil to be improved by one of three optional methods, as applicable, to be chosen by the applicant:

- Direct report of the number of acres to which compost or other organic matter will be added to soils in quantities that meet the standards identified in Table 1 above (from Gravuer 2016)

- Direct report of the number of acres to be impacted by other healthy soils practices (e.g. to which mulch or cover crops will be added; or on which cover cropping or reduced tillage will be implemented)

- Calculation of the number of acres of soil to be increased by at least one rating class using the Cornell Soil Health Assessment (e.g. from the 0-20 range to the 20-40 range, etc) in Figure 1 above (from Moebius-Clune et al 2016) due to soil organic matter amendments or other activities. Percentage of organic matter in the soil body will need to be calculated using a soil test to determine rating class.

b. Project Type 2: Conservation Easements

Sustainable Agricultural Lands Conservation Program (SALC):

- Calculation of acres of agricultural soil conserved by projects funded under the SALC program by map-based estimation of acres of Prime Farmland, Farmland of Statewide Importance, Unique Farmland, Farmland of Local Importance (as defined by the Farmland Mapping and Monitoring Project) to be protected through avoided conversion and ongoing management.

CAL FIRE Forest Health Program

- Calculation of acres of forest soil conserved by projects funded under the Forest Health program by map-based estimation of acres of forest soil to be protected through avoided conversion and ongoing forest management.

High Speed Rail (HSR) program (and any other relevant transportation and sustainable communities programs with offset activities)

- Calculation of acres of agricultural soil conserved to offset impacts of the HSR program, by map-based estimation of acres of Prime Farmland, Farmland of Statewide Importance, Unique Farmland, Farmland of Local Importance (as defined by the Farmland Mapping and Monitoring Project) to be protected through conservation and ongoing management.

  and/or

- Calculation of acres of wetland soil conserved for wildlife habitat to offset impacts of the HSR program, by map-based estimation of acres of wetland soil to be protected through avoided conversion and ongoing management.

c. Project Type 3: Production of Soil Amendments

Waste Diversion Program; Dairy Digesters and Research Development Program (DDRDP); Alternative Manure Management Practices (AMMP):

- Estimation of acres of soil to be potentially indirectly improved by calculation of the number of acres of soil potentially improved by a quantity of manufactured compost or digestate, by dividing the quantity of compost/digestate manufactured in both high- and low-nitrogen, and moist and dry, varieties by the mid-point of the respective recommended ranges for croplands using the Gravuer Method in Table 1 above.

d. Project Type 4: Land Use Conversion

High Speed Rail (HSR) program, CalSTA Transit and Intercity Rail Capital Program (TIRCP), Caltrans Low Carbon Transit Operations Program (LCTOP), SGC Affordable Housing and Sustainable Communities (AHSC), Transformative Climate Communities (TCC) programs:

- Calculation of acres of high-quality soil converted through map-based estimation of acres of Prime Farmland, Farmland of Statewide Importance, Unique Farmland, and Farmland of Local Importance (as defined by the Farmland Mapping and Monitoring Project) to be converted by projects proposing to construct new facilities outside of existing urban areas.

CNRA Urban Greening program, CAL FIRE Urban and Community Forestry (UCF), and CDFA Alternative Manure Management Practices (AMMP programs:

- We recommend that development of any guidance to assess soil health and conservation co-benefits from these land conversion programs wait until future years. Given the uncertainty of the existence of significant soil health and conservation co-benefits from projects funded by these programs, it would not be advisable to require applicants to accept the data acquisition and calculation burden that would be required to use the available methods to assess these co-benefits.

e. Project Type 5: Restoration or Greening Activities

Wetlands and Watershed Restoration program:

- This program requires project applicants to report on soil organic carbon to calculate carbon sequestration rates (for CARB's GHG quantification methodology). Since this already requires extensive data collection on the wetland soils, applicants can additionally calculate the number of acres of soil to be increased by at least one rating class using the Cornell Soil Health Assessment (as described above).

CAL FIRE Forest Health, Urban and Community Forestry programs, and High Speed Rail (HSR) program (and any other relevant transportation and sustainable communities programs with restoration or greening offset activities):

- We recommend that development of any guidance to assess soil health and conservation co-benefits these restoration and greening programs wait until future years. Given the uncertainty of the existence of significant short-term soil health and conservation co-benefits that are quantifiable by currently available methods from projects funded by these programs, it would not be advisable to require applicants to accept the data acquisition and calculation burden that would be required to use the available methods to assess these co-benefits.

ii. Methods for measurement after award of CCI funds:

The methods for measurement in phase two (monitoring) parallel the methods in phase one (prediction) above, amounting to an estimation of the acreage of soil impacted by each project:

- Reporting of acres of soil improved by the Healthy Soils, SWEEP, and Wetlands and Watershed Restoration programs using one of the same three optional methods described above.

- Reporting of the acres of high-quality soil conserved by easement projects funded under the SALC program using the same method described above.

- Reporting of the acres of soil potentially improved by a quantity of manufactured compost or digestate by projects funded under the Waste Diversion, DDRDP, and AMMP programs using the same method described above.

- Reporting of the acres of agricultural or natural soil converted to urban use by projects funded under the HSR, TIRCP, LCTOP, AHSC, and TCC programs using the same method described above.

We recommend that development of any guidance to assess soil health and conservation co-benefits from restoration and greening or land conversion projects in the CNRA Urban Greening, CAL FIRE Urban and Community Forestry (UCF) and AMMP programs wait until future years. Given the uncertainty of the existence of significant soil health and conservation co-benefits from projects funded by these programs, it would not be advisable to require applicants to accept the data acquisition and calculation burden that would be required to use the available methods to assess these co-benefits.

iii. Schedule

Because these methods and tools are generally straightforward modifications of tools and guidance that already exist, we anticipate that we could develop draft co-benefit assessment methodology within two months of CARB's instruction to proceed.

iv. Data needs

The data that a CCI applicant will need to provide to use the methods recommended above will vary according to the CCI program to which they are applying for funds:

For the Healthy Soils, SWEEP, and Wetlands and Watershed Restoration programs, applicants will need to provide:

- The number of acres to which compost or other organic matter will be added to soils in quantities that meet the standards identified in Table 1 above (from Gravuer 2016), or on which other healthy soils practices will be implemented

  - or -

- The percentage of organic matter in a soil body before, and a projection of the percentage of organic matter in the same soil body after, a proposed application of organic matter amendments or other activities. Percentage of organic matter in the soil body will need to be calculated using a soil test to determine rating class.

For the Waste Diversion, DDRDP, and AMMP programs, applicants will need to provide:

- The tonnage (either moist or dry) of compost or digestate to be produced by the proposed project
- The approximate carbon-to-nitrogen ratio of compost or digestate to be produced by the proposed project

For the SALC program, applicants will need to possess:

- A mapped representation, or detailed description, of the boundaries of their proposed project site, to compare to county-level FMMP maps of farmland classification

For the HSR, TIRCP, LCTOP, AHSC, and TCC Programs, applicants will need to possess:

- A mapped representation, or detailed description, of the locations of any proposed facilities on previously undeveloped land outside of existing urban areas, to compare to county-level FMMP maps of farmland classification

IX. Bibliography

Akala, V.A. and R. Lal. 200[1]. Soil organic carbon pools and sequestration rates in reclaimed mine soils in Ohio. *Journal of Environmental Quality* 30: 2098-2104.

Albaladejo, J., J. Lobez, C. Bois-Fayos, G. Barbera, M. Martinez-Mena. 2008. Long-term effect of a single application of organic refuse on carbon sequestration and soil physical properties. *Journal of Environmental Quality* 37: 2093-2099.

Bauer, A. and A.L. Black. 1992. Organic carbon effects on available water capacity of three soil textural groups. Soil Science Society of America Journal 56: 248-254.

Brown, S. and M. Cotton. 2011. Changes in soil properties and carbon content following compost application: Results of on-farm sampling. *Compost Science and Utilization* 19(1): 88-97.

Brown, S., K. Kurtz, A. Bary, and C. Cogger. 2011. Quantifying benefits associated with land application of organic residuals in Washington State. Environmental Science and Technology 45(17): 7451-7458.

California High Speed Rail. 2016. Sustainability Report December 2016. Available at http://www.hsr.ca.gov/docs/programs/green_practices/sustainability/Sustainability_Report_Dec_2016.pdf as of August 26, 2017.

Cornell Cooperative Extension. 2008. Soil Organic Matter. Agronomy Fact Sheets: Fact Sheet 41. Available at http://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet as of April 27, 2017.

DOC [CA Department of Conservation]. 2017a. Important Farmland Data Availability. Available at http://www.conservation.ca.gov/dlrp/fmmp/Pages/county_info.aspx as of April 26, 2017.

DOC [CA Department of Conservation]. 2017b. Important Farmland Mapping Categories and Soil Taxonomy Terms. Available as of April 20, 2017 at: http://www.conservation.ca.gov/dlrp/fmmp/Documents/soil_criteria.pdf

DOC [CA Department of Conservation]. 1997.*California Agricultural Land Evaluation and Site Assessment Model Instruction Manual*. Sacramento: DOC.

Gravuer, K. 2016. Compost Application Rates for California Croplands and Rangelands for a CDFA Healthy Soils Incentives Program. Sacramento: CDFA.

Grismer, M.E., and M.P. Hogan. 2005. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe basin: 2. Bare soil assessment. *Land Degradation and Development* 16: 397–404.

Khaleel, R., K. Reddy, and M. Overcash. 1981. Changes in soil physical properties due to organic waste applications: A review. *Journal of Environmental Quality* 10: 133-141.

Lindsey, B. and T. Logan. 1998. Field response of soil physical properties to sewage sludge. *Journal of Environmental Quality* 27: 534-542.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindlebeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe, and G.S. Abawi. 2016. Comprehensive Assessment of Soil Health – The Cornell Framework Manual, Edition 3.1. Geneva, NY: Cornell University.

NRCS [Natural Resources Conservation Service]. 2015. Soil Quality Indicators. Available at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=stelprdb1237387, as of April 27, 2017.

NRCS [Natural Resources Conservation Service]. 2008. SSURGO Percent Soil Organic Matter for California. Available at https://databasin.org/datasets/8cb1acdc738d4c9196435195b13bf972, as of June 22, 2017.

NRCS [Natural Resources Conservation Service]. 2001. Guidelines for Soil Quality Assessment in Conservation Planning. Washington DC: USDA.

O'Geen, A., S. Southard, and R. Southard. 2008. *A Revised Storie Index for Use with Digital Soils Information*. University of California Division of Agriculture and Natural Resources Publication 8335.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, D., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267: 1117-1123.

Rawls, W.J., Y.A. Pachepsky, J.C. Ritchie, T.M. Sobecki, and H. Bloodworth. 2003. Effect of soil organic carbon on soil water retention. Geoderma 116: 61-76.

Ryals, R., M. Kaiser, M. Torn, A. Berhe, and W. Silver. 2014. Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils. *Soil Biology & Biochemistry* 68: 52-61.

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., and Douglass,

J. 2016. *InVEST +VERSION+ User's Guide*. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Storie, R. 1978. *Storie Index Soil Rating*. University of California Division of Agricultural Science Special Publication 3203.

Storie, R. and A.E. Wieslander. 1948. *Rating Soils for Timber Sites*. Soil Science Society Proceedings 1948.

USDA [United States Department of Agriculture]. 1961. Land Capability Classification. Agriculture Handbook No. 210. Washington, DC: USDA Soil Conservation Service.

Varvel, G.E. and W.W. Wilhelm. 2010. Long-term soil organic carbon as affected by tillage and cropping systems. *Soil Science Society of America Journal* 74: 915-921.