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AES White Paper: Defining Soil Health Within the Context of Ecosystem Health—A Framework

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A healthy ecosystem has been defined as being stable and sustainable—able to maintain its organization, autonomy and resilience to stress over time (Costanza 1992). Such a healthy ecosystem provides a myriad of services. Conversely, an ecosystem that is unhealthy, as are so many of the earth's ecosystems, suffers from impaired functions and is far less capable of providing ecosystem services. Borrowing terminology from human health, such unhealthy ecosystems are said to suffer from ecosystem distress syndrome (EDS) (Rapport et al. 1985).

A solid understanding of the health of an ecosystem relies on understanding its various components (e.g., soils, biota, air, water, nutrients) and their interactions. This understanding, in turn, relies on data acquired via careful selection of appropriate measures that indicate resilience, vigor and organization (Rapport et al. 1998a). It depends on the use of technically and scientifically sound, repeatable assessment methods as well as understanding correlations and interactions among indicators. The overarching goal of defining ecosystem health is to create efficient and effective ways to restore, manage and monitor natural resources to achieve critical performance milestones as defined in management plans, and to engage in public education and consensus among land managers and other stakeholders. A working definition of soil health from the Natural Resources Conservation Service (NRCS 2019) is: "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans."

To consider soil health within an ecosystem framework, we consider the functions and interactions of the soil ecosystem within the larger ecosystem. How does soil health contribute to ecosystem health? Soil health, in contrast to soil quality, addresses the living and dynamic attributes of soil that are associated with soil biota, soil biodiversity, and soil food web structure and function (Pankhurst et al. 1997).

Compilations of soil health indicators, measurements and monitoring protocols have or are being proposed for diverse purposes by various organizations such as, Soil Health Institute (2019), GreenAmerica (2019) and others. These catalogs (e.g., crop fertilizer recommendations and testing procedures; soil loss allowance guidance centered around "t" values; fertilizer recommendations driven by crop yield rather than unintended consequences of degraded water quality, declining water supplies, declining food nutritional density, and others) may or may not provide useful information, but in isolation, not organized and integrated as part of an ecosystem health framework, their usefulness is limited.

In contrast, we propose using ecosystem health as an organizing and interpretive framework to better measure and interpret soil health, and to apply findings to ecosystem and soil management. By its very nature, an ecosystem approach includes interactions among measured soil attributes. It also examines trophic interactions—something missing from most catalog approaches. In short, within an ecosystem health framework, soil health indicator measurements are diagnostic of system health, not simply measured components of soil.

Today, a "regenerative working landscape" perspective that follows an ecosystem health paradigm focuses on diversity and ecosystem functioning, rather than on crop production, yield or conventional economically profitable outcomes from the land. Successful land management efforts in human-modified landscapes typically are found to incorporate the following approaches:

- **A stewardship relationship and commitment between people and ecological resources.** Such a relationship contrasts with a "status quo, laissez faire attitude" where management is left to a few experts with little or no engagement with potential stakeholders. Connecting people and ecological resources is vital in determining the future fates of the working landscapes and the larger ecosystem. In highly altered areas, where remnant ecosystems are vulnerable to impacts by surrounding land-uses, humans must play an active role in the management, restoration, and monitoring to ensure improvement or, at least, perpetuation of healthy ecological systems in working and conservation landscapes.

- **A commitment of funds and policies for maintaining ecological health, restoration, management and monitoring programs**. Political will and associated funding must be investments people are willing to make in natural resources and stewardship. Successful natural resources restoration and management programs have appropriate recurring annual line-item levels of funding support.

- **Adaptability of management strategies using new information.** Natural systems show variable responses to management and restoration initiatives and actions. Following nature's lead, the fundamental basis of an adaptive management program is the ability to modify protocols to account for measured changes documented by monitoring data. Adaptive management, solidly based on accurate, measured data, is perhaps the only way to create continually improved approaches that can solve emerging and continually changing ecological challenges.

- **A commitment to design with prudence, humility, and open eyes—to learn from the ecological system and to not foreclose on future options**. Programs focused on learning from an ecosystem with humility are typically more successful than those that do not take advantage of opportunities to learn and adapt.

Ecosystem Health—Indicators of Biological, Soil, Water and Air Systems

Ecosystem health has been used as a guiding principle to evaluate land suitability and management needs *(*Apfelbaum and Chapman 1999*)*. This concept is widely applicable to the environmental management of agricultural and range land, where healthy systems are achieved through integration of the biological integrity of ecosystems with the needs and values of humans (Rapport et al. 1998b).

The following broad indicators correlate with goals of achieving ecosystem health. To date, these indicators have been primarily associated with non-agricultural or other non-working, or "wild" lands. Under this proposed framework, however, we are applying these indicators to ecosystem and soil health specifically on working landscapes.

1. **Stable soils**. With few exceptions, all vegetated, natural systems in the world have stable soil systems. Stable soils are defined as those that have long-lived, deep-rooted plants, continuous cover, typically 50% pore space, and good aggregate stability and resistance to erosion—all resulting in aerobic soils with freely occurring, year-round aeration and gas exchange, diverse organic inputs from living roots, appropriate soil structure, and optimized functional capacity. In general, unstable soils are indicative of failing soil and ecosystem health. Failing health is expensive to repair. For example, in oak woodlands, unstable soils generally result below the dense shade of invasive shrubs that prevent growth of soil stabilizing herbaceous plants such as native grasses and sedges. On grazed or cultivated lands, acceptable levels of erosion (such as NRCS's arbitrary "t" value—an annual level of theoretically replaceable soil erosion loss) have been used to suggest "acceptable" annual erosion losses. However, this logic of acceptable losses does not incorporate either in situ soil organic carbon or biological system declines from such factors as use of caustic fertilizers, regular tillage, non-maintenance of crop residues, compaction and changing water relations, irrigation and dewatering and aerobic decomposition of organic matter. As a result, the concept of "t" values, particularly combined with crop on crop cycles that deplete soils, does not support the definition and intent of soil stability.

2. **Predominance of sustainable native plant populations**. Historically, native plant communities were dominated by species that persisted or slowly moved into the various regions of the world, with climate change as a principle agent driving their distributions. Today, humans introduce (inadvertently and advertently) plants to new areas at rapid rates, with many introduced species threatening the well-being of established native plant and animal communities. Until recently, neither native plant populations nor year-round cover of living

plant tissue on agricultural lands have been considered functional elements used to increase and/or maintain soil and ecosystem health. This is beginning to change as now even annual cover cropping, and plantings of polycultures used to simulate natural systems, are used to contribute both to soil health as well as restoring diverse native plant communities (Vukicevich et al. 2016).

3. **Diverse plant and animal communities**. In general, native plant communities are composed of a plethora of plant species that contribute to the character and structure of habitat that, in turn, supports animal communities. Unhealthy plant communities tend to have low diversity, are often dominated by one or a few plant species, and, concomitantly, often support a depauperate animal community. For decades, agricultural systems and similar working landscapes types have focused on the production of specific crops at the cost of all non-commercial plants and animals. Pesticides used to protect crops are indiscriminate in their killing of all insects as well as rodents and other small mammals, mildews, rusts, and other fungi. These procedures that essentially encourage the reduction of abundance and diversity of all life forms have resulted in drastic overall ecosystem simplification, and directly influence the capability of nutrients to be stored and cycled throughout an ecosystem.

4. **Water quality, at appropriate rates and volumes.** Poor water quality, as well as high rates and volumes of runoff, are associated with human land disturbance primarily resulting from the development and impairment of soils and vegetation systems on uplands. This situation is exacerbated by the drainage of wetlands that would, in healthy conditions, contain, use, filter, and slowly release water to surface and groundwater sources, mitigating erosion. In general, healthy soils in healthy ecosystems tend to retain water (e.g., storage in soil systems, containment in landscape depressions, increased lag time because of increased resistance to the rate of water movement as measured by the Manning coefficient). The net result is the dissipation of a larger percentage of water through evaporation and infiltration than is the case on degraded areas. Land managers, and society in general, have been slow in realizing and understanding the link between water quality and land use. Until recently, in many regions of the world, even in water-starved irrigated agricultural landscapes, soils and water have been viewed merely as exploitable natural resources. The predominant irrigation technologies (e.g., center pivot and other spray technologies, flood irrigation with open ditch distribution systems) while useful, are vastly wasteful means of supplying agricultural water; they significantly alter the watershed, the quality of water and soil, and the overall soil ecosystem.

5. **Capacity to change and adapt to disturbance**. The ability of ecological systems to achieve resiliency—to restructure or reassemble after disturbance—is a key attribute of healthy ecosystems. Unhealthy systems tend to degrade further or even collapse after additional disturbance. Looks can sometimes be deceiving. Although land that is the result of long-standing disturbance cycles may become re-vegetated, this mostly likely will be by weedy invasive plants and animals rather than diverse native plant and animal communities of ecosystems untrammeled by humans. Historically, working lands have not had time to morph or adapt to

changes, particularly meteorological changes. Too much or too little water in soil, landscape perturbations such as flooding, drought, wide temperature fluctuations that are cooler or warmer than normal conditions all result in declining yields or outright crop failures. Nevertheless, more recent practices of building soil organic carbon with cover crops, improved grazing methods, and use of alternative cropping systems and rotations have all shown potential to improve the capacity of land to adapt to ongoing disturbances and changing conditions.

Ecological System Health Restoration, Management, and Maintenance

Ecological restoration has been broadly defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). Typically, an effort is made to alter a site to emulate a defined, indigenous, historic (pre-settlement-like) ecosystem. The objective is to reestablish the structure, function, diversity and dynamics of a specific reference native ecosystem. The overarching goal is to repair or reestablish functioning ecosystems.

Under this paradigm, ecological restoration encompasses management practices intended to maintain ecological integrity. In highly disturbed settings, and situations where funding and labor resources are limited, achieving recovery of a complex biologically productive historic landscape may be an unreasonable goal. Nevertheless, restored systems still can reflect historic systems, modified as necessary to be appropriate for the current edaphic and hydrological conditions. As an example, hydrologic conditions that historically supported wet prairie or sedge meadow communities today may be more supportive of shallow marsh plant assemblages because of artificial impoundments, excavated ponds and large quantities of directed surface runoff from adjacent developed uplands. Likewise, historic soils may have been removed, buried under deep sediment deposits, or degraded by agricultural practices, necessitating a creative restoration response that accounts for these altered conditions. Additionally, adherence to strict guidelines for reestablishment of plant species using local genetic strains may be unreasonable, even undesirable, owing to changes in conditions due to climate change. Whereas local seed sources should be collected and utilized or acquired from reputable seed dealers and used preferentially in restorations, there may be practical limitations of available seed sources and producers.

Many agricultural/grazed landscapes are systems that have been depleted of vital factors such as nutrients, structure, and biodiversity. They are ripe for the application of ecosystem health restoration. In a working landscape, such as a farm or grazed pasture, the restoration of ecosystem health and functions is typically ignored by current soil health advocates relying on existing definitions of soil health. This results in continued "symptom management" rather than true soil health restoration. Currently, most soil heath indicators and measures are framed to identify soil health deficiency symptoms (e.g., pH, levels of P, N, K and other nutrients) and thus do not advance the foundational thinking needed to change the way soils are managed. We must frame the future using ecosystem health and ecosystem restoration as foundational concepts and then deploy testing and monitoring to understand and achieve ecosystem health as the foremost goal. A successful crop yield becomes a beneficiary of the primary goal of restored ecosystem health, rather than the primary goal itself.

Defining and Measuring Soil Health in the Context of Ecosystem Health

Soil health is to be measured within the context of ecosystem health. Thus, we propose to use not only indicators of soil variables, but also contextual ecosystem variables. Both rely on use of field indicators that are not only practical and cost effective to measure, but result in collection of primary data that are relevant to desired outcomes. The **Appendix** contains a more detailed table of soil health indicators derived from published scientific papers, NRCS, Soil Health Institute, Soil Health Partners, and other sources used by Applied Ecological Services to develop the suite of measurements and indicators used in many of our projects. Selected short lists of measurements and indicators are summarized in Tables A-C.

The following considerations have been important in framing the soil and ecosystem health measurements outlined in Tables A-C:

1. All primary measures of soil/ecosystem health use standard reputable scientific methods that have been well established and used by scientists, agronomists, agencies (e.g., USDA, EPA, DOE) and other land managers as standard procedures documented to support scientific understandings and reliable testing.
2. All primary methods are intended to produce reliable quantitative data. Over time, re-measurement can produce data sets that can be subjected to rigorous statistical testing.
3. The secondary methods are primarily for use during intervening years, between the primary measurement periods. Secondary indicators can be used to develop trends and trajectories. Such indicators, however, may not be as useful for developing robust statistical testing.
4. For all primary measurements of soils, a minimum of one-meter (1m) depth is required to understand the dynamics of both the more variable and unstable soil carbon in the upper soil depths, and the extant, often more recalcitrant carbon that is removed from the active management zone and experiences greater temperature and moisture fluctuation, greater disturbances, higher biological activity, and higher rates of organic matter turnover. A snapshot of surface or at-depth carbon dynamics independent of each other can provide misleading and misinterpretable carbon trend information because of the differing processes acting on soil strata in space and time. Sampling to a 1m depth allows for interpretation of long-term organic and inorganic carbon dynamics throughout the soil profile, and offers opportunities for scaling carbon content and modeling soil carbon across landscapes when associated soil bulk density measurements are included. Additionally, in many soil types and plant communities, disproportionately larger quantities of soil organic carbon may occur at depths greater than 30 cm—the customary crop soil fertility and crop plant rooting zone that is conventionally sampled.

Table A provides criteria for choosing both soil and ecosystem health indicators associated with ultimate desired outcomes. The suite of measurements and indicators is able to be effectively deployed in working lands and wild lands.

Table A: Indicators of Soil and Ecosystem Health

Criteria	Desired Outcomes
Useful	Improve soil structure and function
Cost-effective	Improve ecosystem resiliency
Represents 'vitals' of an ecosystem	Improve ecosystem carbon stocks
Sensitive to management changes	Improve water infiltration, water holding capacity, and water quality
Standardized sampling and analysis methods	Minimize external inputs, improve nutrient storage and cycling
Repeatable	
East to interpret; Known ranges and trends	

Variables used to assess soil health directly rely on technical measurements that can be assessed using standard technical field and linked laboratory methods, and field-deployed tests (Table B). The two levels of measurements proposed are defined as follows:

- **Technical Measurements** are standard field and laboratory tests proposed for assessment of baseline conditions as well as periodic follow-up monitoring. They are crucial for accurate comparisons of changes over time, such as every 5-10 years. A structure for deploying the technical methods can be found in VM0021 Soil Carbon Quantification Methodology, v1.0 (The Earth Partners 2012).
- **Field-Deployable Variable Measurements** can be field measured under an annual monitoring framework by farmers, agronomists, and others, to track trends between the years when technical measurements are deployed. In addition, field deployable measurements would be conducted each year, congruent with technical measurements, to provide a basis for comparison over time between methods.

Table B: **Soil Health Variables**

Soil Variable	Technical Measurement	Field-Deployable Measurement
Total soil carbon	Dry combustion corrected for inorganic C	Solvita® test (CO_2-burst/respiration)
Bioavailable Nitrogen	ACE protein test	Solvita® Labile Amino Nitrogen (SLAN) test
Soil bulk density	Undisturbed core of known volume (soil dependent)	Surface and subsurface hardness - Penetrometer
Soil infiltration rate/saturated hydraulic conductivity	Lab saturated using flow cells & Field saturated-DualHead	DualHead Infiltrometer
Macroaggregate stability	Wet Aggregation	In-field soil slake test
Soil pH and electrical conductivity (EC)	Lab soil:water mix using pH and EC meter	Field probe to test pH and EC
Soil temperature and moisture	In-field sensors/data loggers buried at multiple depths	Field thermometer and soil volumetric water content probe
Soil genomics	Metagenomics	MinION
Soil enzyme activities/microbial biomass C and N	Lab bioassays; fumigation-extraction or PLFA	Solvita® test or 'Soil your Undies' decomposition test
Soil and vegetation insect/arthropod diversity	Field collection/Sweeps/Pitfall traps/Burlese funnel	Scheduled point surveys

Ecosystem health variables are crucial to understanding broader relationships between ecological landscapes and land management regimes. Table C provides a short list of most commonly measured variables and basic field-deployable methods. Standard methods and standard data forms for measurement of these and other Ecosystem Health variables are summarized in "The Restoring Ecological Health to Your Land Workbook" (Apfelbaum and Haney 2012).

In addition, there are differences in the level of effort (sample sizes and techniques) between technical data collection designed for rigorous statistical testing and correlation with other variables, and those efforts designed for ongoing maintenance monitoring. For example, for assessing breeding birds, linear transect sampling conducted in concert with breeding bird territory mapping is used to provide measurements of species richness, species absolute abundance (numbers of individuals of each species present), and territory size (reflecting food resources and habitat partitioning). If desired, these data can be used to calculate the overall annual metabolic energy demand of the bird community. By contrast, a point count monitoring method without territorial mapping provides only metrics on species richness, frequency of occurrence, and relative abundance. There is also a difference in effort. The transect method requires a minimum of four (4) surveys, while the point count method typically can be accomplished with two (2) surveys, though more are recommended. The same types of sampling effort and data details can be extrapolated for reptiles, mammals, and insects. Habitat continuity and connectivity typically are measured using standard field mapping procedures summarized using GIS tools. Monitoring relies on GIS tools and field confirmation procedures.

Table C: Ecosystem Health Variables

Ecological Variable	Technical Measurement	Field-Deployable Method
Ecosystem connectivity and continuity	GIS mapping and field groundtruthing of habitat types, habitat quality (species richness, and management tenure). Calculation of connectivity, habitat heterogeneity measures and index.	GIS-assisted mapping
Breeding birds	Permanent 100 m transects replicated in cover types; Emlen technique	Permanent sampling locations, transects or point sampling
Insect and arthropod abundance and diversity	Permanent 100 m transects replicated in cover types; Emlen technique	Permanent sampling locations, transects or point sampling
Herptile abundance and diversity	Breeding call surveys; sunny day transect surveys	Permanent sampling locations, recording traps
Mammal abundance and diversity	Permanent camera traps, trapping, sign/tracking techniques	Permanent sampling locations, field cameras

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Appendix: Catalog listing of suggested soil health indicators as derived from academia (see review paper by Bünemann et al. 2018), Soil Health Institute (2019), NRCS (2019), Soil Health Partnership (2019), and others. Citations provided in table indicate a general consensus on a method for determination of indicator values. Additional methods (citations not included) exist for all soil health indicators listed. Note: bolded entries represent AES priority indicators.

Soil Health Indicator	**Indicator Type**	**Function**	**Method**	**Units**	**Field Deployable**	**Citations**
Electrical Conductivity	Chemical	Reactivity, soil fertility	EC meter 1:1 soil:water	mS/m	Y	Smith and Doran 1996
Sodium Adsorption Ratio	Chemical	Water dynamics, nutrient cycling	Saturated soil paste extraction	ratio		NRCS, 2005 National Soil Survey Handbook
Soil Temp	Physical	Reactivity	Field probe at multiple depths	°C	Y	
pH	Chemical	Reactivity, soil fertility	pH meter 1:2 soil:water		Y	Mclean, 1982
Bulk Density	Physical	Soil structure, water dynamics, fertility, nutrient cycling	Undisturbed core corrected for rocks; excavation	g/cm^3; Mg/m^3		
Penetration Resistance	Physical	Soil structure/fertility	Penetrometer	Mpa, kg/cm^2; $tons/ft^2$; PSI	Y	
Macroaggregate Stability	Physical / influenced by biology	Soil structure and resiliency	Wet aggregation	score; µm		Kemper and Rosenau, 1986; Arshad et al., 1996
Slaking	Physical	Soil structure and resiliency			Y	Herrick et al., 2001
Soil Crusts	Physical	Soil structure and resiliency	line-intercept; thickness/resistance		Y	
Soil Erosion	Physical	Soil structure and resiliency	NRCS RUSLE2		Y	
Soil Stability Index	Physical	Soil structure and resiliency		ratio		
Soil Porosity	Physical	Soil structure and resiliency	Gravimetric method			Danielson et al. 1986
Sand-Silt-Clay Composition	Physical	Soil structure, reactivity	Pipette method	%		
Soil Texture	Physical	Soil structure and resiliency	USDA texture triangle	g/kg	Y	
Infiltration	Physical	Water dynamics	DualHead Infiltrometer	cm/s	Y	

Soil Health Indicator	**Indicator Type**	**Function**	**Method**	**Units**	**Field Deployable**	**Citations**
Available Water Holding Capacity	Physical	Water dynamics	Pressure plate	kg water/kg soil; m^3water/m^3soil		Naeth et al. 1991
Saturated Hydraulic Conductivity (Ksat)	Physical	Water dynamics		µm/s	Y	
Soil Water Content	Physical	Reactivity, water dynamics	TDR Field Probe	ratio		
Runoff	Physical	soil strucutre, resiliency		m^3/s		
Nutrient Leaching	Chemical	soil strucutre, resiliency		mg/L		
Total Soil Carbon	Chemical	carbon storage and cycling	Dry Combustion corrected for inorganic C	%; Mg C/ha		Nelson and Sommers 1996; Sherrod et al. 2002
Total Soil Nitrogen	Chemical	nitrogen cycling	Dry combustion	%; Mg N/ha		Nelson and Sommers 1996
Standard Soil Test: N, P, K, Mg, Ca, Na, CEC, Base Saturation, S, Zn, Mn, Fe, Cu, B	Chemical	soil fertility, resiliency	Region appropriate extraction e.g., Mehlich 1 vs 3	%, cmol/kg, ppm, g/kg		
Labile Carbon	Chemical, Influenced by biology	Carbon cycling and microbial activity				
Permanganate Oxidizable Carbon	Chemical, Influenced by biology	Carbon cycling and microbial activity		Mg C/kg soil		Weil et al. 2003
Particulate Organic Matter	Chemical, Influenced by biology	Carbon cycling and microbial activity		mg/L		Cambardella and Elliot 1992
Short Term Carbon Mineralization	Chemical, Influenced by biology	Carbon cycling and microbial activity				Fronning et al. 2008; Carter et al. 2003

Soil Health Indicator	Indicator Type	Function	Method	Units	Field Deployable	Citations
Substrate Induced Respiration	Chemical, Influenced by biology	Carbon cycling and microbial activity				
Soil Respiration	Chemical, Influenced by biology	Carbon cycling and microbial activity	Solvita®CO2; IRGA	mg/kg; g C/m^2/d; µmol/m^2/hr		
Active Carbon	Chemical, Influenced by biology	Carbon cycling and microbial activity		mg/kg		
Mineralizable Carbon	Chemical, Influenced by biology	Carbon cycling and microbial activity		g C/kgsoil; umol/hr/gsoil		
Bioavailable Nitrogen	Chemical/Influenced by biology	Nitrogen cycling and microbial activity	Solvita® Labile Amino Nitrogen (SLAN) test; ACE protein	mg/kg	Y	Schindelbeck et al. 2016
Potentially Mineralizable Nitrogen	Chemical/Influenced by biology	Nitrogen cycling and microbial activity	7-day incubation	mg/kg		Drinkwater et al. 1996
Nitrogen Mineralization	Chemical/Influenced by biology	Nitrogen cycling and microbial activity		µg N/g soil; kg/ha; mg/kg		
Soil GHG emissions (CO2, N2O, CH4)	Chemical/Influenced by biology	nutrient cycling and microbial activity, resiliency	FTIR, Vented Static Chamber	µg/m^2/hr		
Genomics	Biological	community structure and diversity				
Microbial Biomass Carbon and Nitrogen	Biological	microbial activity	fumigation extraction	mmol/kg		
Ester-linked Fatty Acid Methyl Ester (EL-FAME)	Biological	community structure and diversity	EL-FAME			
Soil Protein Index	Biological	community structure and diversity				Schindelbeck et al. 2016

Soil Health Indicator	**Indicator Type**	**Function**	**Method**	**Units**	**Field Deployable**	**Citations**
Phospholipid Fatty Acid (PLFA)	Biological	community structure and diversity	Biochemical assays			Buyer and Sasser 2012
Fungal Indicators	Biological	community structure and diversity				
Soil Enzymes	Biological	microbial activity and nutrient cycling	Biochemical assays; BG, NAG	µmol/g/hr		Deng and Popova 2011
Soil Fauna / Arthropods / Earthworms	Biological	community diversity, resiliency		count	Y	
Soil Pests	Biological	community diversity, resiliency			Y	
Diseases	Biological	community diversity, resiliency			Y	
Crop Yield / Veg Biomass	Biological	community diversity, resiliency		kg/ha	Y	
Weeds	Biological	community diversity, resiliency		count; kg/ha, % cover		
Reflectance / NIR	Physical/Chemical	Soil structure/nutrient cycling; C storage		%; µm	Y	