Smart Solar℠

American Farmland Trust

Solar Soil Health Guide

Safeguarding soils on solar sites from development to deployment

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American Farmland Trust
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American Farmland Trust (AFT) is the largest national organization dedicated to protecting farmland, promoting sound farming practices, and keeping farmers on the land. AFT unites farmers and environmentalists in developing practical solutions that protect farmland and the environment. We work from "kitchen tables to Congress," tailoring solutions that are effective for farmers and communities and can be magnified to have greater impact. Since our founding, AFT has helped to protect more than seven million acres of farmland and led the way for the adoption of conservation practices on millions more. AFT has a national office in Washington, D.C., and a network of offices across America where farmland is under threat.

For more information, visit us at farmland.org

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PHOTO CREDIT: AGRISOLAR CLEARINGHOUSE

Bluewave Agrivoltaics in Palmer MA

About this Guide

Building on American Farmland Trust's Smart Solar℠ Principles,[1] this guide discusses key considerations and practices to safeguard soil health during solar development, from site assessment through design and construction into operations and maintenance (O&M). The intended audience for this guide includes solar developers, engineering, procurement, & construction (EPC) contractors, and policymakers.

Aspects of this guide are tailored to agrivoltaic applications, including grazing and crop production, but the general principles can be applied to any ground-mounted solar project to protect the future agricultural viability of the land. This guide does not cover decommissioning or repowering—those are beyond the scope of this guide and will be topics for future work.

FIGURE 1. Solar Development Lifecycle. This guide covers Site Assessment, Design & Engineering, Site Preparation & Construction, and the early stages of Operations & Maintenance.

Introduction

Across the United States, the acceleration of utility-scale solar development on and near agricultural lands is raising questions about impacts to soil health and farm economies. Solar energy development done well can provide a valuable opportunity for agricultural producers to diversify their revenue. American Farmland Trust advocates for Smart Solar℠, which goes a step further to support farm viability, equity, and soil health while mitigating negative impacts associated with solar development.

Solar siting is largely driven by interconnection capacity, state policy, and local zoning, which constrain the locations where projects can be built.[2] Farmland is frequently targeted for solar development because it tends to be relatively flat, cleared, and well-drained, with access to nearby electrical infrastructure. American Farmland Trust estimates that more than 80% of new large-scale solar projects will be built on agricultural land.[3] Regardless of whether solar projects include dual-use applications such as agrivoltaics or ecovoltaics,[4] protecting soil health should be a priority for solar developers, landowners, contractors, and policymakers to safeguard healthy soils, preserve the critical ecosystem services soils provide, and ensure that farmland can return to agricultural production after decommissioning.

Unique Opportunities and Challenges of Managing Soil Health for Solar

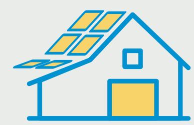
The rapid deployment of solar in rural areas presents an opportunity to improve soil health on millions of acres of agricultural land, especially for projects sited on soils with depleted carbon content from generations of intensive agricultural production.[5] The U.S. Department of Energy's Solar Futures Study estimates a potential land requirement of up to ten million acres of land for solar energy development by 2050.[6] **Under current deployment trends, this suggests approximately eight million acres of farmland in the U.S. may be converted to solar in the next quarter-century.** Key challenges for improved land stewardship on solar sites include construction disturbances, variable light and water distribution within the array, and communication and coordination across disparate stakeholders.

Soil compaction from construction is the most obvious and damaging consequence of solar development, potentially leading to erosion, runoff, and soil degradation. Research conducted by the National Renewable Energy Laboratory, the University of Minnesota, and the Great Plains Institute identified soil compaction as the single most important factor for stormwater management and water quality for solar sites.[7] This

Smart Solar℠ Principles

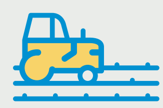
PRINCIPLE 1

Prioritize solar siting on buildings and land not well suited for farming (unless agrivoltaics).



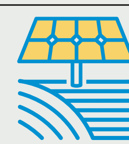
PRINCIPLE 2

Safeguard soils and the ability for land to be used for agriculture.



PRINCIPLE 3

Grow agrivoltaics for agricultural production and solar energy.



PRINCIPLE 4

Promote equity and farm viability.

FIGURE 2. AFT Smart Solar℠ Principles (AFT)

guide outlines practices that developers and contractors can adopt to minimize construction disturbances and support the future agricultural viability of solar sites, providing an opportunity to improve community relations.

In contrast to an open pasture or field, solar sites feature rows of solar modules that intercept sunlight and precipitation, creating heterogeneous growing conditions across a field that complicate land management decisions. Additionally, the solar infrastructure can present an obstacle to conventional farm machinery used for soil amendments and seeding, increasing the difficulty and labor costs of managing vegetation within the array. This guide identifies specific solar design considerations and site preparation practices to support healthy vegetation through the life of the project.

Solar projects inherently require coordination across diverse teams and stakeholders, including finance, legal, construction, operations, maintenance, landowners, neighbors, permitting officials, and more. Dual-use solar introduces another layer of complexity by adding agricultural producers and ecologists to the mix. This guide also provides a roadmap for developers to engage with landowners and agricultural producers early in project development to improve soil health outcomes.

Soil Health—Why it Matters

Healthy soils contribute value to solar development by improving community perceptions, increasing site stability, and reducing cost and regulatory risk associated with stormwater runoff, erosion, and nutrient pollution. Additionally, healthy soils on a solar site will safeguard the agricultural productivity of land, improving the viability of farming through the life of the solar project and beyond.

Showing the promise of growing crops under solar panels at Rutgers' Agricultural Research and Extension Center.

The importance of soil goes far beyond agriculture—soil is the foundation of all terrestrial ecosystems. Topsoil, rich in soil organic matter critical to soil health, is a finite resource that takes thousands of years to form, but it can be destroyed far more quickly. Soils support plant growth through nutrient cycling, provide a medium for root growth, and offer access to water and minerals. They are also a critical component of global-scale earth processes like the Earth's carbon (C) and water cycles, serving as the largest terrestrial store of carbon.

Beyond supporting plant growth that provides food for humans and wildlife, healthy soils provide numerous ecosystem services, including water infiltration, filtering and storage, carbon sequestration, erosion control, and nutrient recycling through decomposition. Degraded soils often require costly intervention to restore these services and maintain productivity levels.

Soil Health Principles

Broadly, all soil health management practices fall under one or more of four principles that work together to promote or maintain soil organic matter levels. These four principles are:

1. **Minimize disturbance** (minimize tillage, compaction, and chemical inputs);
2. **Maximize soil cover** (protect the soil surface with living plants or plant residues);
3. **Maximize biodiversity** (supporting as many living species per land unit as possible); and
4. **Maximize days in living roots** (keep as robust a living plant community on the soil as possible for as much of the time as possible) (*Soil Health | Natural Resources Conservation Service*, 2025).

The application of these principles is critical to protecting the function and productivity of agricultural ecosystems, though specific practices may vary across cropping systems, climates, and soil types.

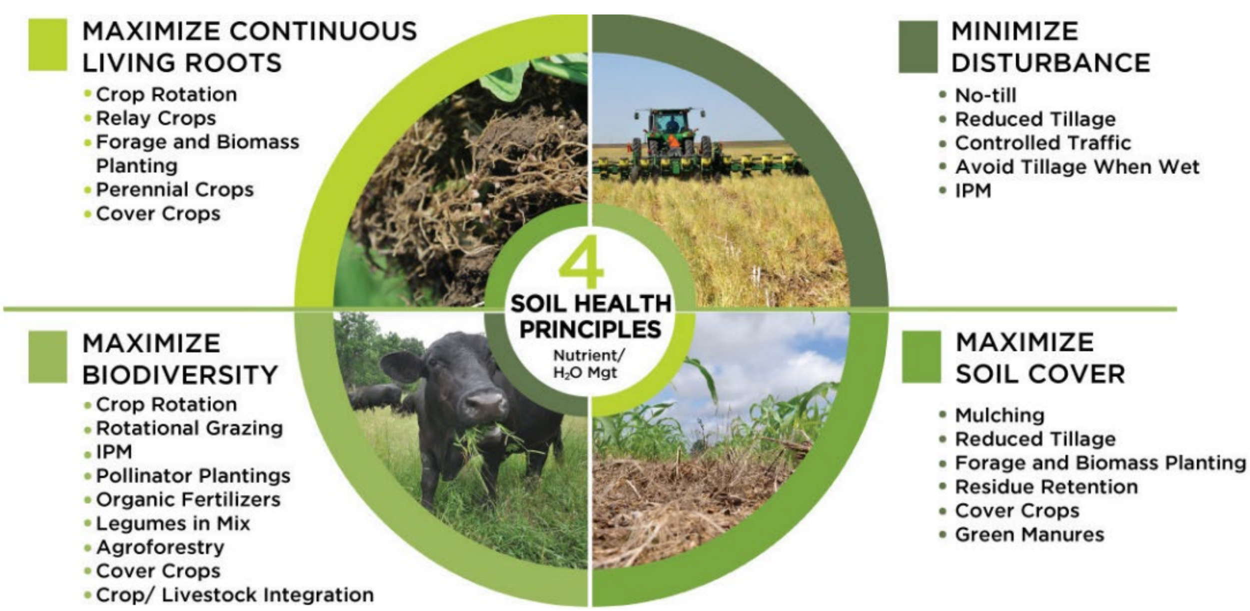


FIGURE 3. Principles of Soil Health and Associated Practices (USDA NRCS).

Produce growing under panels at Rugers' Agricultural Research and Extension Center.

The State of Solar Soil Health Research

Given the relative nascency of the solar industry and long-term nature of soil health changes, research into soil health on solar sites is limited, though rapidly evolving. Krasner et al. (2024) is the most comprehensive meta-analysis of soil health research on solar sites to date, compiling data from 18 studies to assess impacts of photovoltaics on soil health metrics.[8]

Considering soil carbon as a proxy for overall soil health, Krasner and co-authors found 3 studies that reported lower soil carbon and two studies that reported increased soil carbon within solar arrays. Two of the studies noted significant differences in soil carbon beneath the panels versus in the interspace between rows, with the interspace area generally having higher soil carbon content. Additionally, two of the papers considered sites grazed by sheep, but sheep were excluded from the study areas in both cases.

To assess the impacts of solar grazing on soil health and pasture quality, the American Solar Grazing Association (ASGA) and American Farmland Trust collected data from 28 grazed and three non-grazed solar sites for a 2024 conference paper presented at the Agrivoltaics World Conference.[9] ASGA and AFT found that grazed sites tended to have higher soil organic matter content and higher soil pH (i.e., less acidic soil) compared to non-grazed sites, and a small — but not statistically significant — improvement in pasture condition scores on grazed sites.

These findings demonstrate that soil health outcomes on solar arrays are highly nuanced and vary depending on site context, land management history, climate, vegetation selection, and management practices. Further work is needed to increase the number and diversity of sites being studied, track long-term soil health outcomes, and standardize soil health research methodologies on solar sites, all of which are key goals of Argonne National Laboratory's Solar Soil Project.[10]

Site Assessment

Historically, solar developers have focused on technical, economic, and legal considerations in assessing potential solar sites. As solar deployment accelerates, local opposition is simultaneously increasing.[11] To maintain their social license to operate, developers need to improve their siting and land stewardship practices by considering the social, environmental, and biological contexts of their projects. During site assessment, developers can set themselves up for better project and soil health outcomes through soil testing, detailed mapping, and thoughtful engagement with the landowner and local agricultural producers.

Pre-Planning & Engagement

Prior to stepping foot on site, developers can learn a great deal by mapping the site and interviewing farmers and landowners who have worked the land. Generally, the goal of this diligence is to learn about the prior use of the land, site variability, soil and water drainage characteristics, and, where applicable, assess feasibility and constraints for agrivoltaic applications.

Farmer attendees, AFT, and Rutgers staff learning the ins and outs of agrivoltaic systems at Rutgers Agricultural Research and Extension Center.

Soil Surveys & Mapping

The United States Department of Agriculture's Natural Resources Conservation Service (NRCS) provides detailed soil maps through its Web Soil Survey tool.[12] This mapping tool provides invaluable data on soil types, slopes, and natural resource concerns related to erosion, runoff, soil health, and susceptibility to compaction. The Web Soil Survey data is not a replacement for field observations and data collection, but this data is an excellent starting point to begin informed conversations with landowners about the nuances of their property prior to conducting a full soil survey or geotechnical study.

Within the Web Soil Survey, one can start by defining the Area of Interest (AOI), then checking the Soil Map to see the breakdown of soil types and slopes within the AOI. Next, using the Soil Data Explorer, there are three key tabs to explore for useful data: Suitabilities and Limitations for Use, Soil Properties and Qualities, and Ecological Sites. Full instructions and documentation for the Web Soil Survey tool can be found on the NRCS website.[13]

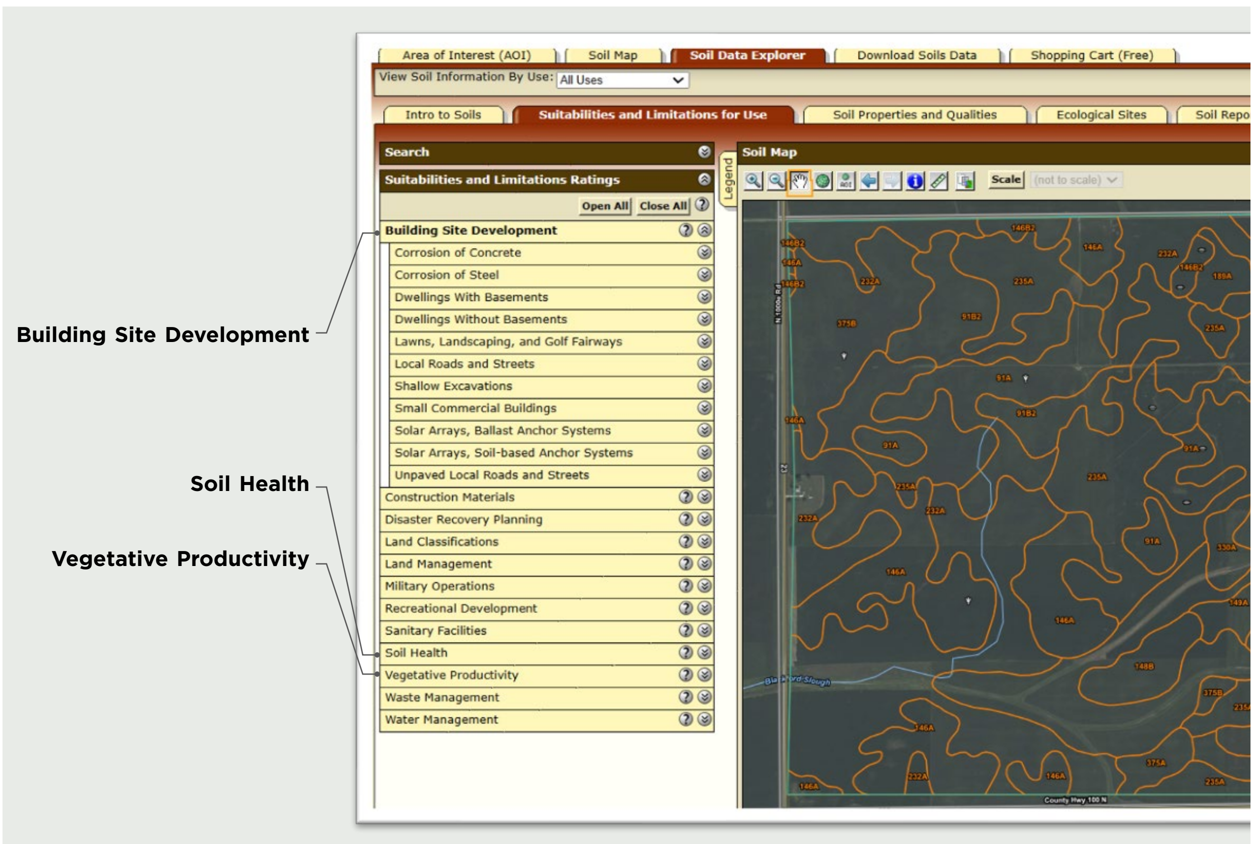


FIGURE 4. Web Soil Survey Tool – Suitabilities and Limitations for Use (USDA NRCS).

Under the Suitabilities and Limitations for Use tab, there are ratings to assess the viability of different solar mounting systems, risks to soil health during and after construction, and suitability for crop or range production on the site. Developers are specifically encouraged to explore the following soil ratings:

- **Building Site Development** – identify potential limitations on types of solar ground-mounts.
  - Solar Arrays
    - Ballast Anchor Systems
    - Soil-based Anchor Systems
- **Soil Health** – understand potential concerns for soil health during and after construction.
  - Fragile Soil Index
  - Organic Matter Depletion
  - Soil Susceptibility to Compaction
- **Vegetative Productivity** – classifies the suitability of land for crop or range production.
  - Crop Productivity Index
  - Range Production
    - Favorable Year
    - Normal Year
    - Unfavorable Year
  - Yields of Irrigated/Non-Irrigated Crops

The next tab, Soil Properties and Qualities, presents high-level data on soil properties, including physical, chemical, and biological properties. For the purposes of solar development, it is recommended to focus on the Soil Health Properties, specifically looking at Bulk Density, Organic Matter, and Soil Reaction (pH). These ratings provide an approximate baseline for soil health prior to development and are useful for understanding what soil amendments may be necessary to restore soil health to this baseline pre- and post-construction.

Finally, the Ecological Sites tab links to Ecological Site Descriptions (ESD) that provide qualitative and quantitative information about the land, including details about the site characteristics, plant communities, and management practices. Within the ESD, the "Ecological Dynamics" section lists typical vegetation species that thrive on the site, which may be useful for establishing vegetation management plans and selecting seed mixes well-suited to the site.

The ratings provided in the Web Soil Survey are based upon data collected for almost a century at a scale ranging from 1:12,000 to 1:63,360, and thus are presented at a broader scale than that of an individual site. It is not a substitute for on-site soil sampling and analysis. However, this data can be useful to establish an approximate baseline of a site's soil properties and potential implications for engineering design, soil amendments, vegetation management, and construction practices to preserve soil health. Soil geospatial and attribute data (Soil Survey Geographic Database (SSURGO) can be downloaded for use with GIS software (e.g., QGIS, ArcGIS) on the gSSURGO webpage.[14]

Monarch Caterpillar on Milkweed under Lake Pulaski solar panels.

Farmer & Landowner Interview

Developers are encouraged to engage intentionally with agricultural landowners early in the development process to better understand the land characteristics and land-use history. Understanding these aspects of the site can better inform design and management, especially if the project is planned for agricultural dual-use. Specific recommendations for this interview process include:

1. **Ask about the existing farming operation.**
   a. What crops and/or livestock are currently grown on the land?
   b. What management practices (e.g., grazing plan, tillage, aerial spraying) are in place?
   c. What machinery and farming implements are used in the current operation?
   d. In which direction does the farmer typically operate within the field?
2. **Ask about the site and land management history.**
   a. What is the prior use of the land?
   b. Is there tile drainage on site?
   c. How does surface water flow on the site? How are neighboring parcels affected by surface water on the site?
   d. Is there anything known to be different from the existing soil maps (e.g., seasonal ponding, rocky areas, underground hazards, rubble from prior structures)?
   e. Are there underground irrigation and water lines to work around?
   f. Are there wetlands on site? Have wetlands been formally delineated?
   g. Are the NRCS soil classification maps accurate?
3. **Ask about future farm operations and needs.** For agrivoltaics projects, AFT recommends consulting with the farmer early in the development process and working with them throughout the project design process.
   a. What crops and livestock are expected to be raised on the site?
   b. What machinery and implements will be used?
   c. What are the dimensions of the machinery and implements for critical operations (e.g., height, width, turning radius)?
   d. If using tillage, what is the type of tillage used, frequency, and the tillage depth?
   e. What type of irrigation and water systems will be used?
   f. What are the water requirements for the planned crops and livestock?
   g. Are there other infrastructure requirements, such as fencing or water tanks?

Community Engagement

Solar development is incredibly challenging, as evidenced by the fact that only 14% of solar projects that enter interconnection queues get built.[15] Early investment in community engagement is increasingly recognized as key to an effective project development process. Sharing information about how projects will be designed and operated to minimize impacts on agricultural soils, neighboring properties, and local watersheds can be a valuable aspect of community engagement. Developers are strongly encouraged to exceed minimum community engagement requirements for permitting and engage in dialogue about farmland impacts and soil health considerations directly with neighbors and the local community surrounding a project. This can include hosting town halls, sponsoring community events, meeting with neighbors and local leaders, and collaborating with community-based organizations.

While community engagement is not necessarily focused on soil health practices, concerns related to soil quality impacts are a common theme reflected in surveys about solar on farmland.[16] By engaging openly and transparently with communities early in the development process—before the design is finalized—developers can proactively address community concerns, build trust, and develop strategies to mitigate potential impacts on soil and water. Developers are encouraged to share how they incorporate this guide in their project planning and community outreach efforts.

PHOTO BY AMERICAN FARMLAND TRUST

Austin Kinzer from American Farmland Trust meets with farmers and ranchers in Colorado during spring 2024 to learn about their perspectives on agrivoltaics.

Soil Health Testing for Solar Sites

Soil health testing is critical to create a baseline for the physical, chemical, and biological indicators of soil health. Soil health cannot be evaluated by a single measurement. Researchers and practitioners use a wide range of indicators to assess soil health comprehensively. Table 1 details the four most important indicators of soil health recommended to test in a solar array.

SOIL HEALTH METRIC	WHAT IS IT?	WHY DOES IT MATTER?
Soil Organic Matter (SOM)	Soil organic matter tests measure the fraction of soil composed of organic matter, including living microbial biomass, plant residue, and plant, animal, and microbial matter in varying states of decomposition.	SOM plays a vital role in maintaining soil health by improving soil structure, water retention, and nutrient availability. It also supports a diverse community of soil organisms, which are essential for nutrient cycling and overall soil fertility.
Aggregate Stability	Soil aggregate stability refers to the ability of soil particles to stick together and form aggregates, which are clusters of soil particles. Aggregate stability tests measure the ability of soil to maintain its structure against disruption from forces such as wind, water, and tillage.	When soil aggregates are stable, they resist breaking apart under stress, such as heavy rainfall, which helps reduce soil erosion. Soil aggregates also provide the structure necessary to create pore space in the soil for aeration, root growth, microbial activity, and the infiltration and retention of water.
Soil Respiration	Soil respiration tests measure the release of carbon dioxide from soil as an indicator of biological activity within the soil. Soil respiration is the process by which soil organisms break down organic matter and release carbon dioxide (CO_2) into the atmosphere.	This process is a key part of the carbon and nutrient cycle and indicates the level of biological activity in the soil. Essentially, soil respiration measures how active and healthy the soil ecosystem is. It reflects the efficiency of decomposition of SOM, resultant nutrient cycling, and the energy flow within the soil.
Soil Compaction	Soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This can happen due to heavy machinery, foot traffic, or even natural processes like rainfall. Soil compaction tests measure the bulk density of the soil, indicating the fraction of pore space to allow for root growth, water infiltration, and aeration of the soil.	Compacted soil becomes dense and hard, making it difficult for roots to grow and for water and air to move through the soil. This can lead to poor plant growth, increased runoff and flooding, and reduced soil health.

TABLE 1. Key soil health metrics relevant for solar sites and why they matter.

Methodology

Methods for sampling and interpreting soil tests vary by region, soil type, and type of testing, so it's important to work with local experts and follow the soil sampling approach recommended by your chosen lab, agronomic partner, or third-party testing institution. Developers should contact the local land-grant university and extension service for guidance on soil testing, and reference Argonne National Laboratory's Solar Soil Recommended Methods.

For soil health testing in the context of a solar site, AFT recommends five steps:

1. **Identify a local soil health testing partner** (e.g., land grant university, agronomic partner, third-party lab). The United States Department of Agriculture's National Institute of Food and Agriculture (NIFA) maintains a directory of land-grant universities.[17]
2. **Divide the site into smaller units** based on soil types and prior land management.
3. **Follow laboratory protocols for sampling area,** points, and number of samples for each unit.
4. **Select sample areas within the PV array** to account for variable light and moisture conditions within the array—at a minimum, soil samples within the array should include points directly beneath the panels and points in the interrow space between the panels.
5. **Record sampling area and points** so comparable samples can be collected in the future.

For sites in the Northeast and Midwest, the Cornell Soil Health Lab is widely used and provides comprehensive soil health testing with accessible, actionable results. For sites in the West and South, it is recommended to use both a local nutrient lab and a soil health testing package. Many State Departments of Agriculture maintain lists of state-recommended laboratories on their websites. Costs for soil health testing vary between labs, but developers should generally budget approximately $100 to $150 per sample for testing, which covers soil organic matter, aggregate stability, soil respiration, and compaction analysis. For more precise estimates, developers can reference cost sheets for their selected laboratory, or use the Solar Soil Analytical Cost Estimator tool on Argonne National Laboratory's Solar Soil project webpage.


PHOTO BY AMERICAN FARMLAND TRUST

Alan Bailey, AFT's Midwest Smart Solar Specialist, conducts soil testing at a solar site.

Timeline

Soil health should be assessed on-site pre- and post-construction using a soil health testing package that includes compaction analysis. Results from these assessments provide baseline conditions so that post-construction impacts can be evaluated, remediated, and tracked. For ongoing tracking, the samples should be collected periodically (ideally, once a year for the first five years, then every three to five years thereafter) throughout the project life at approximately the same time of year, ideally in the spring prior to the commencement of spring planting or soil amending, or in the fall post-harvest (or at the end of the growing season).

Soil Visual Assessment

The US Department of Agriculture's Natural Resources Conservation Service has established two key visual assessment tools that can be useful for monitoring soil health:

1. **Pasture Condition Scoring**[18]
   This is a method to assess the productivity and condition of a pasture for grazing or hay production, ideally completed just before a pasture is going to be grazed or harvested.
2. **Cropland In Field Soil Health Assessment**[19]
   This is a diagnostic tool used to identify potential soil health resource concerns, which includes 11 different indicators of soil health. The optimal timing to assess each indicator varies, but generally, this assessment is best performed before or during the growing season while there is adequate moisture in the field.

Solar Design and Engineering

Modern ground-mounted solar projects have an expected lifetime exceeding 30 years, so design decisions made today will affect soil health and land stewardship practices for decades into the future. The first step for developers interested in safeguarding soil health is to engage with their engineering team—whether internal or subcontracted—to evaluate the tradeoffs that their design decisions will have for the construction and operation of the array. To design a solar array that safeguards soil health, AFT recommends minimizing disturbance, accounting for shade impacts from the panels, and consulting with an agricultural producer or expert.

Minimize Disturbance

Agricultural soil is an irreplaceable resource, formed over many millennia from natural processes including glacial movement, plant decomposition, and biological activity. Ideally, topsoil should be left in place; when this is not possible, topsoil should be treated as a valuable resource and conserved for future use. To prevent degradation of soil quality, topsoil and subsoil should never be mixed.

Adhering to the soil health principle of minimizing disturbance, engineers should work to avoid grading as much as possible. In practice, this may include selecting trackers with a greater slope tolerance and modifying site layouts to avoid areas where greater slope variation would necessitate grading. By designing arrays to avoid grading, developers can reduce capital costs related to machinery, fuel, and labor. Additionally, developers and engineers should prioritize the use of driven piles or helical piles rather than concrete footers to minimize the land area impact of their designs.

Account for Shade Impacts

Solar design engineers should account for the shading impacts of their designs, which will affect the viability and resilience of vegetation within solar arrays. Selection of seed mixes used to establish vegetation within arrays should include shade-tolerant species to account for variation in light availability. In the interest of maximizing soil cover for soil health, it is best to avoid designs that will result in excessive shade through large portions of the array.

FIGURE 5. Heavy use area beneath panels with bare soil resulting from livestock hoof traffic (AFT).

Vegetation in heavily shaded areas will generally be less resilient to traffic from humans, livestock, and machinery. Additionally, livestock frequently congregate in shade during hot weather, which can result in higher hoof traffic on less resilient vegetation.

Ground-level irradiance beneath the array will be affected by many factors, including, but not limited to array height, row spacing, tracking system, module type, racking layout, and local climate. In general, tracking systems will result in a more uniform irradiance distribution compared to fixed-tilt systems. Similarly, higher module mounting heights will result in a more uniform irradiance distribution than systems with lower clearance. Solar arrays designed to allow more light—and more consistently distributed light—underneath will make it easier to establish and maintain healthy, resilient vegetation.

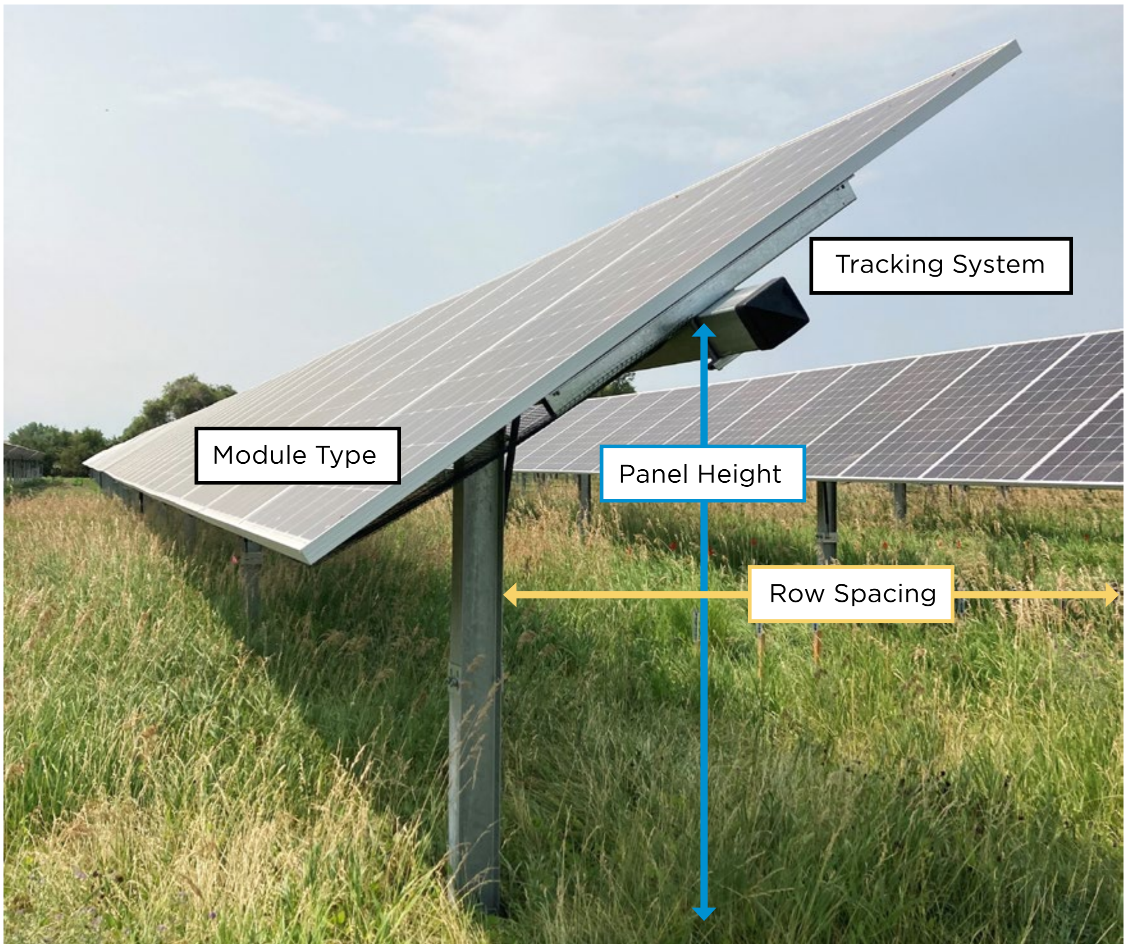


FIGURE 6. High-quality vegetation beneath a single-axis tracking solar array at Jack's Solar Garden in Longmont, Colorado, with highlighted factors that affect ground-level irradiance distribution (AFT).

Technical Assistance Program for Agrivoltaics Systems (TAPAS) field day at Rutgers Agricultural Research and Extension Center Photo by American Farmland Trust.

Consult a Farmer or Rancher

Particularly for agrivoltaics projects, agricultural producers and experts should be consulted early and often during the design process to ensure that the site will be suitable for agricultural use. Design engineers and construction firms should be careful to design and construct the array to avoid damaging water drainage, pipes, and irrigation systems. Additionally, irrigation and water needs for crops and livestock should be accounted for during the design phase and built into the project plan. Similarly, developers should work with their agricultural partners on a water contingency plan to ensure reliable access to water through the life of the project.

Specific to grazing projects, farmers should be consulted in selecting a pasture mix, establishing a vegetation management plan—ideally with rotational grazing—to control weeds and invasive species, ensuring adequate fencing for livestock, and maintaining tight wire management to avoid livestock entanglement. Additionally, combiner boxes and power electronics should be elevated or otherwise protected from livestock interactions.

Site Preparation and Construction

To safeguard long-term soil health within solar arrays, topsoil should be protected, and prevention of soil compaction needs to be a primary consideration during site preparation and construction. In practice, developers & EPC contractors should focus on soil amendments, vegetation, vehicle traffic, laydown areas, grading, and trenching to minimize negative soil health impacts.

Soil Amendments

Having completed baseline soil testing during site assessment, any necessary soil amendments should generally be added prior to any construction work. Marginal agricultural lands, which are often chosen for solar sites, may have acidic, alkaline, or sodic soils, requiring the addition of lime or sulfur to balance the soil pH and support plant growth. Similarly, agricultural soils on solar sites may benefit from the addition of organic amendments such as compost, manure, or biochar to improve soil organic matter content.[20] It is much more efficient to do this prior to construction so that standard farm machinery can be used to apply soil amendments.

FIGURE 7. Example of farm machinery used to spread fertilizer on a field (Photo by RAUCH Landmaschinefabrik GmbH, CC BY-SA 3.0).21

Vegetation Establishment

After soil amendments have been applied, the next step is to establish vegetation to achieve durable soil health outcomes. The preferred approach is to maintain and enhance existing vegetation on-site, but seeding may be necessary to increase vegetative cover or establish healthy perennial species suitable for project needs. Typically, a locally appropriate pasture mix, native seed mix, or cover crops are preferred so that robust roots can be established in advance of construction to minimize compaction and protect soil health. Ecological Site Descriptions from NRCS can be a useful tool to understand the local ecology and identify vegetation species appropriate for the site. Healthy vegetation on site can help mitigate compaction, erosion, and stormwater runoff during construction. Developers are strongly encouraged to build time for vegetation establishment into their pre-construction timelines to minimize compaction resulting from construction machinery on bare soil.

For grazing projects, developers should coordinate with their solar graziers to develop a grazing plan and consider grazing the site prior to construction if appropriate. Additionally, grazing sites should ensure that the seed mix prioritizes both shade-tolerant species and species appropriate for the selected livestock, soil type, and climate, while avoiding species that are toxic or unpalatable. Developers are encouraged to work with local extension or NRCS field offices to identify appropriate seed mixes.

Vehicle Traffic

The concept of "controlled traffic" has existed in agriculture for decades and can be readily adopted by solar developers with minimal cost impacts.[22] Simply put, developers should limit vehicle traffic to designated lanes and avoid vehicle traffic through the field in wet conditions when the soil is much more susceptible to compaction. This will minimize the extent of soil compaction through construction and preserve soil health.

FIGURE 8. Example of heavily compacted soils resulting from vehicle traffic in wet conditions (Windwärts Energie GmbH / Mark Mühlhaus)

Roads, vehicle turnarounds, and equipment laydown areas should be identified in advance—prioritizing areas that are already compacted or easier to mitigate post-construction—and contractors should be held accountable for sticking to these designated areas as much as possible. Other strategies that can be used to minimize compaction include:

- Laying down mulch or mats in equipment laydown areas and other heavy-use areas;
- Using tracked machinery instead of wheeled machinery;
- Lowering tire pressure on wheeled machinery;
- Using lighter vehicles to move equipment through the field; and
- Limiting vehicle passes through the field.

Minimizing soil disturbance is preferred, but most projects will require some amount of grading or trenching. Any time soil is being relocated for roads, grading, or trenching operations, and especially when working with subprime soils, topsoil should be removed and stored separately from the subsoil for later reapplication. To the extent that new roads are constructed, it is important that developers and EPCs adhere to best practices for erosion prevention and drainage construction. Only clean fill, uncontaminated by chemicals or refuse, should be used in road construction to prevent contamination of agricultural lands.

For trenching, narrower cuts are preferred to reduce the land area affected. Project developers should be well-versed in state guidelines to protect agricultural soils during site preparation; for example, New York has instituted detailed solar project requirements to mitigate impacts and protect soil health.[23]

Post-Construction Remediation & Soil Testing

After construction is complete, the next steps are remediation and soil testing to understand and mitigate construction impacts. Remediation typically involves the removal of construction materials and waste, soil decompaction, and reapplication of seed mix where appropriate. Soil decompaction can be made more difficult by the presence of solar infrastructure, which obstructs access, highlighting the need to minimize compaction during construction. AFT recommends conducting soil testing for bulk density using a penetrometer at regular intervals within the field before and after decompaction to determine whether additional remediation is necessary to restore the soil.

Alan Bailey, AFT's Midwest Smart Solar Specialist, conducts soil testing at a solar site.

PHOTO BY AGRISOLAR CLEARINGHOUSE

Operations & Maintenance

The operational phase accounts for the majority of a project's life. How the site is managed and operated will drive community perceptions of the project and the solar industry more broadly. The start of commercial operations also represents a shift in the stakeholders engaged on the project—a different set of contractors responsible for operations and maintenance and, depending on the developer's business model, possibly a new asset owner. To improve soil health outcomes on a solar site through operations, project operators need to coordinate effectively across stakeholders, ensure successful vegetation establishment and management, continue to monitor soil health indicators, and utilize adaptive management practices to learn what practices work best for the novel ecosystem of a solar site.

Stakeholder Coordination

A common pitfall of community engagement is when developers and asset managers cease engaging with the community after the project is completed. With project lifetimes measured in decades, it's important for asset owners and O&M teams to develop long-term relationships in the communities where solar projects are sited. Successful relationship-building is critical to support the long-term growth of the solar industry.

With that in mind, developers, asset owners, and O&M teams should ensure that they coordinate with landowners, neighbors, and any on-site agricultural partners to ensure that solar O&M activities do not disrupt other operations. For example, O&M teams should avoid spraying herbicide on windy days when it may impact neighboring fields. With any type of on-site agricultural dual-use, O&M teams should coordinate scheduled or reactive maintenance activities with their agricultural partners and be diligent about maintaining fencing and gates that could impact livestock enclosures or predator/pest access to the site.

Vegetation Establishment & Management

Under ideal conditions, robust vegetation has been established prior to construction, construction impacts are minimal, and vegetation can rebound quickly after construction. The reality of large-scale solar is that even well-intentioned projects with best practices observed may result in heavy impacts to vegetation during construction. This may require care, attention, and time to successfully re-establish healthy vegetation post-construction. Stormwater permits typically require revegetation to at least 70% of pre-disturbance levels, but this should be viewed as the bare minimum.

Depending on the site and vegetation selection, reseeding can be done through broadcasting, drill seeding, or hydroseeding methods. Establishing healthy, perennial vegetation may require irrigation to establish, particularly in arid climates. Additionally, native vegetation may take years to establish and successfully outcompete weeds. The first few years of vegetation management may require additional weed management with mowing and herbicide application to prevent weeds from dominating on-site.

For grazing sites, there may be pressure to bring livestock on-site as quickly as possible, but sites may be at increased risk of overgrazing when vegetation is still recovering from construction impacts. Developers should work closely with graziers to ensure that timing and stocking rates are appropriate for the site and aligned with the grazing plan. Developers should also ensure that their grazing partners have contingency plans to reduce stocking rates and relocate livestock if needed to prevent overgrazing.

PHOTO BY AGRISOLAR CLEARINGHOUSE

Ongoing Soil Health Testing & Adaptive Management

Building soil health is a long-term process, and the results of land management practices may not be immediately evident. Especially within the first few years of a project's life, it is important to monitor the site closely and use adaptive management techniques to adjust as needed. In the context of a solar site, adaptive management means consistently evaluating how conditions on the site are evolving and adapting operations, vegetation management, and grazing plans to account for uncertainty and changing conditions.

Ideally, soil health testing can be incorporated into routine maintenance plans, including annual soil testing in the first five years of the project's operations, and follow-up soil testing every three to five years thereafter. Soil testing should be completed at the same time each year, either in the spring or the fall. Using the results from these tests, developers can coordinate with their operations and maintenance teams to address potential soil health concerns, apply additional soil amendments as necessary, and adapt O&M practices to protect soil health. This is especially important in the first few years of a project's life to ensure that declines in key soil health metrics are identified and addressed as early as possible.

Conclusion

By applying an informed understanding of basic soil health principles to development and construction, solar companies can lower their operational costs, improve community perceptions of their projects, and avoid potential liabilities related to poor soil health management, such as high-consequence stormwater runoff events that can affect water quality and neighboring properties.

Limited data exists on soil health outcomes in solar arrays, and there is ongoing work to establish standardized methodologies and soil sampling protocols to create larger, more consistent, and more useful datasets. Much of the existing literature addressing soil health on solar sites has been approached through the lens of stormwater management and water quality, rather than agriculture. Further research is needed to fully understand the soil health impacts of solar arrays and how they can be used to benefit farmers and provide ecosystem services.

As the solar industry continues to mature and expand its footprint, there needs to be a shift in mindset from a myopic focus on short-term outcomes to a long-term view of land stewardship and community-building around solar sites. The industry's rapid growth is impressive, but to sustain that growth, the solar industry needs to be a better neighbor in the communities where it operates.

Additional Resources

Argonne National Laboratory

- Solar Soil Project Homepage
- Ground-Mounted Solar and Soil Related Ecosystem Services Project: Recommended Field and Analytical Methods for Measuring Soil Constituents at Ground-Mounted Solar Energy Facilities
- Recommended Methods Report

National Renewable Energy Laboratory & Great Plains Institute:

- Photovoltaic Stormwater Management Research and Testing (PV-SMaRT) Project Homepage
- Best Practices: Photovoltaics Stormwater Management Research and Testing (PV-SMaRT)

United States Department of Agriculture, Natural Resource Conservation Service:

- Conservation Considerations for Solar Farms
- Conservation Guidance for Utility-Scale Solar Projects

New York State Department of Agriculture and Markets

- Guidelines for Solar Energy Projects – Construction Mitigation for Agricultural Lands

Chesapeake Bay Program – Scientific and Technical Advisory Committee

- Best Management Practices to Minimize Impacts of Solar Farms on Landscape Hydrology and Water Quality

Endnotes

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