SCHOOL OF ENVIRONMENT AND NATURAL RESOURCES

Baseline Assessment of Soil Health in Ohio

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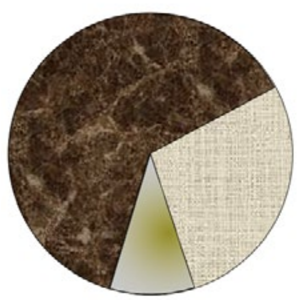
INTRODUCTION

As our understanding of soil health advances, farmers are increasingly interested in assessing and improving soil health on their farms. Several commercial labs now offer soil health packages, typically made up of tests that reflect biological, chemical, and physical components of the soil. But generating values in a lab is only the first step. A frame of reference for what constitutes a typical, low, or high soil health value is essential for establishing a baseline for improvement. In this report, we provide a state-wide baseline of soil health values from Ohio to help farmers and landowners assess and track soil health in their fields.

Soil organic matter. Soil organic matter influences most soil properties, and so soil health tests that focus on organic matter are of particular interest. Although it is a critical component of soil, total organic matter changes slowly over time. It can take years or decades for changes in management practices to be reflected in total organic matter. Because of this lag, researchers often focus on the biologically active fraction of organic matter (Figure 1). Active organic matter is only 5-20% of the soil's total organic matter, but is very important for crop nutrition since nutrients in this fraction are rapidly cycled and taken up by crops. Organic matter is primarily made up of carbon, the backbone of life and the currency that plants and the soil food web use to cycle nutrients and energy throughout the soil.



Passive
- Very stable organic material
- Extremely slow decomposition and cycling
- 60 – 80% of OM
- Turnover: decades - centuries

Slow
- Intermediate organic material
- Slow decomposition and cycling
- 10 – 30% of OM
- Turnover: years - decades

Active
- Recently deposited organic material
- Rapid decomposition and cycling
- 5 – 15% of OM
- Turnover: days - few years

Figure 1. Pools of organic matter in the soil. Each pool has important and unique functions. The active pool is the source of rapidly cycled nutrients driven by soil biological communities.

Three relatively new tests measure the active pool of organic matter: 1) Permanganate Oxidizable Carbon (POXC), 2) Respiration, and 3) Soil Protein. These tests each provide unique information about the active organic matter of a soil. They are complementary and related, reflecting the rate and size of the pool of nutrients that are cycled within the soil. The larger the pools, the more fertile and resilient a soil will be.

Permanganate Oxidizable Carbon (POXC). POXC, also known as active carbon, is a simple test that uses a weak oxidizing solution to measure readily available carbon. Oxidation is the chemical process of decomposition with oxygen. Just as a fire uses oxygen to release energy (heat) from wood (carbon source), soil microorganisms use oxygen to derive energy from soil organic matter. The more oxidation that happens, the more active carbon there is in the soil. In a POXC test, we induce an oxidation reaction to measure a microbially processed pool of organic matter that is often associated with soil minerals and is therefore an early indicator of soil organic matter building. Research has shown POXC is sensitive to recent management changes that improve soil health (cover crops, tillage, rotations, etc.).

Soil Respiration. Soil Respiration is a method that measures the burst of CO_2 from a dried soil over 24 hours after it has been re-wetted with water. Drying and wetting cycles occur naturally in soils. When soils dry down, organisms go into a resting state to survive. This method measures how fast the soil food web can 'wake back up' and become active again. Carbon dioxide (CO_2) is the product of oxidation of active organic matter. (We can use the same analogy here as burning wood with a fire.) The more CO_2 that is respired, the more active the microbial community is in the soil. Note the Solvita® test is based on this method. This test is also very sensitive to changes in management.

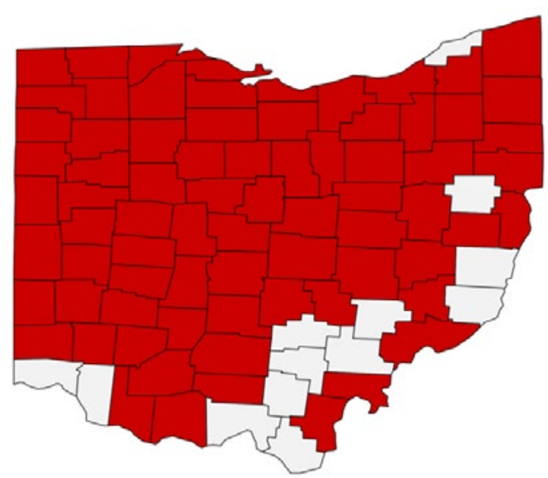
Soil Protein. Most of the nitrogen in soil is in an organic form, and the majority of this is made up of proteins from plants and microbes. Soil protein provides an important source of readily-available nitrogen that is recycled and taken up by plants. Our work shows this pool is a useful indicator of soil nitrogen availability. In addition to plant response, a robust soil nitrogen pool acts as a reservoir for the microbial community and soil resilience in general.

METHODS

This baseline assessment was compiled from 10 distinct projects conducted at Ohio State University from 2015 – 2021. These projects involved mostly on-farm research that either included a simple manipulation or sampled soil in a survey approach. Nearly all soils were from production agricultural fields. Projects were diverse and included field crop fertilizer recommendation trials, certified organic corn fields, soybean fields, hopyards, and tomato fields. See 'Data Source Details' below for more information on the projects included here.

A total of 2,454 soil samples came from 75 counties across Ohio (Figure 2). Soils were most commonly a single soil sample per field, but no more than 10 soil samples per field. We excluded 12 organic soils from our dataset (organic matter values >15%), which represented <0.5% of observations, bringing our total to 2,442 soils. Organic soils differed enough from mineral soils to be considered separately, but we unfortunately did not have sufficient organic soils to include in an independent analysis.

Figure 2. The Ohio counties (red shaded) where soil samples were collected from for this baseline soil health assessment (75 out of 88 counties).



Most soils were sampled to 8-inch depth, with the exception of the approximately 400 eFields project soils sampled at 4- and 6-inch depths. Soils were sampled typically in the fall or spring and mailed or transported to the Soil Fertility Lab at Ohio State where they were dried and ground to <2 mm and analyzed for soil health (POXC, Respiration and Soil Protein; soilfertility.osu.edu/protocols). Spectrum Analytic performed routine nutrient analysis (pH, Mehlich-3 nutrients, organic matter via loss-on-ignition) with recommended procedures (NCERA-13, 2015). At the Ohio State Soil Fertility lab, finely ground soils were scanned with a mid-infrared spectrometer to predict soil organic carbon and soil texture (as described in Deiss et al., 2020a, 2020b). Soil was classified first into one of the 12 textural classes, and then further categorized into one of three main soil groups: *Coarse* (sand, loamy sand, sandy loam), *Medium* (sandy clay loam, loam, silt loam, silt) or *Fine* (sandy clay, clay loam, silty clay loam, silty clay, clay) (Soil Survey Division Staff, 1993). Similarly, soils were also divided into three groups based on cation exchange capacity: Sands (<8 meq/100g), Loams (8-16 meq/100g) or Clay (>16 meq/100g). Data were summarized based on percentiles of Low (<25th percentile), Medium (25-50th percentile), High (50-75th percentile) and Very High (>75th percentile).

RESULTS

As expected, soil properties varied greatly across all 2,442 soil samples (Table 1). Fifty percent of the soils had optimal pH values (6.0 – 6.8) and most soils had sufficient Mehilch-3 phosphorus (P) and potassium (K) values. In general, soil test levels were in optimal ranges for grain crops in Ohio (Culman et al., 2020). Soil organic matter ranged from 0.1 to 9.8% for these soils, with 50% of the values falling below and 50% of the values falling above 2.2% (median value). Soil health measures that reflect biologically active organic matter values varied greatly, with median values of 496 mg/kg for POXC, 46.5 mg/kg for respiration and 4.4 g/kg for soil protein (Table 1).

Table 1. Summary of soil data based on percentiles (n=2442).

Variable	Minimum	25th	50th	75th	Maximum
pH	4.2	6.0	6.4	6.8	8.0
Mehlich-3 Phosphorus (mg/kg)	2	27	44	70	969
Mehlich-3 Potassium (mg/kg)	28	105	140	179	633
Cation Exchange Capacity (meq/100g)	1.9	9.1	12.0	15.3	27.5
Organic Matter (%)	0.1	1.7	2.2	2.7	9.8
Soil Organic Carbon (%)	0.6	1.4	1.7	2.1	7.1
Permanganate Oxidizable Carbon (mg/kg)	55	401	496	617	1433
Respiration (mg/kg)	4.4	32.0	46.5	65.3	458.5
Soil Protein (g/kg)	1.5	3.9	4.4	5.3	25.6

CLASSIFYING BY SOIL TYPE

Soil type often needs to be considered when assessing soil fertility test values. For example, sandy soils cannot hold as much Mehlich-3 K as clay soils. Similarly, there is widespread agreement that soil type needs to be considered when evaluating soil health indicators. Soils with more clay are inherently capable of holding more organic matter relative to sandier soils. Because of this variability, we grouped soils by soil type: Coarse (sands, n=242), Medium (loams, n=1,465), and Fine (clays, n=509). We also grouped soils based on cation exchange capacity (CEC), a measure of soil charge that reflects the capacity of soils to hold nutrients and store organic matter: <8 meq/100g (sands, n=392), 8-16 meq/100g (loams, n=1,566), and >16 meq/100g (clays, n=502). Although these groups were mostly related, we found overlap in CECs between soil type. For example, the majority of coarse soils had CECs between 5-10 meq/100g (reflected by the thickness of the ribbon in Figure 3), but there were numerous observations that are above 10 meq/100g. Based on this range, we can consider our two classifications, by soil type and by CEC, as related but certainly not the same.

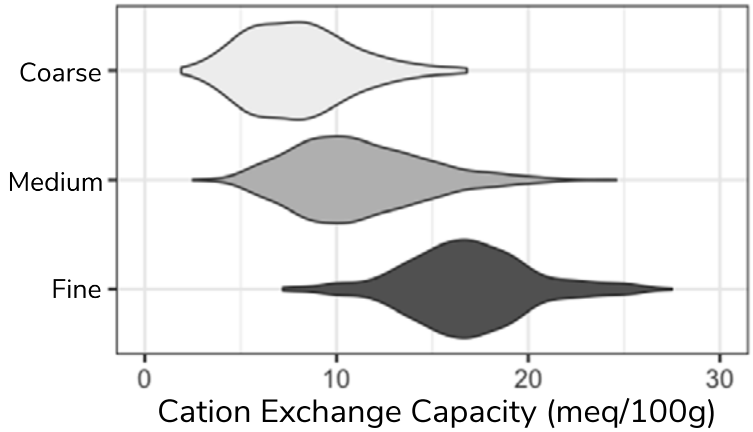


Figure 3. Distribution of cation exchange capacity (CEC) by soil type. The thickness of the ribbon reflects the number of soils with the respective CEC. The majority of coarse soils had CECs between 5-10 meq/100g. Likewise, the majority of fine soils had CECs between 15-20 meq/100g.

Soil texture groupings based on coarse, medium, and fine soils are reported in Tables 2-4 with the distributions illustrated in Figure 4. Soil groupings based on CEC are reported in Tables 5-7 with distributions illustrated in Figure 5. Commercial soil testing labs commonly measure soil CEC, but do not routinely measure soil texture. Because of this, soil CEC will be a more universal reference than texture. For this reason, we report both groupings here. It is unclear which classification is more useful at this point, so growers can use either set of tables as a guideline.

The tables below are intended to provide some reference for typical soil health values based on a given soil type. When a grower gets soil health test results, they can use these tables to see where their soils fall relative to other fields in Ohio. Most labs offering soil health analyses use relatively consistent methods to measure organic matter, soil organic carbon, POXC, and soil protein. Respiration is a method that is measured several different ways and so these values might not line up well if not measured in Ohio State's Soil Fertility Lab. The intention of these tables is to help growers determine if their soil test results are 'good' or 'bad.'

Although it is useful to compare soils against each other, we like to stress that all soils are unique. Rather than rating your soils against others, it is often more fruitful to focus on the trajectory of the soil health in your fields. In other words, tracking changes over time allows you to see how the health of your soil is influenced by your management practices (whether you are starting something new this year or continuing practices). These 3 tests are sensitive to management, so changes (good or bad) should be detectable within a few years. We recommend testing soils every 3-4 years, just as we recommend for tracking routine nutrient analysis (pH, P, K, etc). See the Tri-State Fertilizer Recommendations for more information (Culman et al., 2020).

Classifying By Soil Type

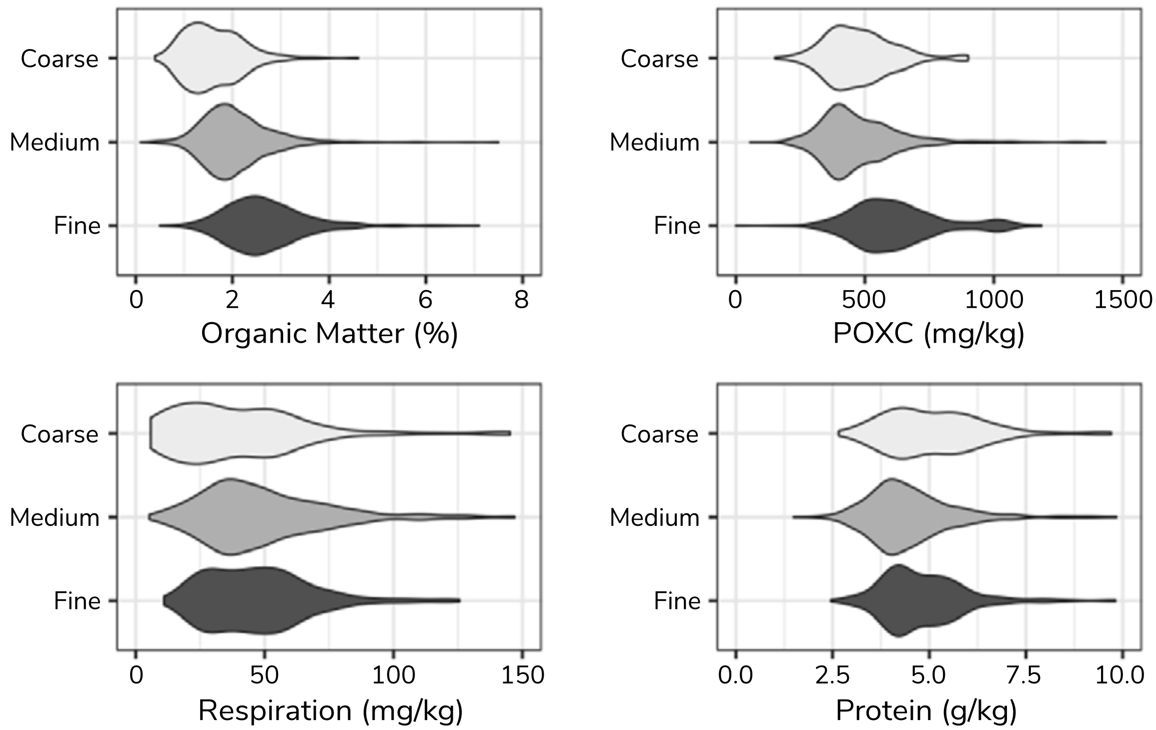


Figure 4. Soil organic matter pool distributions by soil type.

Table 2. Soil health value summary of COARSE soils.

Variable	Low	Medium	High	Very High
Organic Matter (%)	<1.2	1.2 - 1.6	1.6 - 2.1	>2.1
Soil Organic Carbon (%)	<1.3	1.3 - 1.5	1.5 - 1.8	>1.8
Permanganate Oxidizable Carbon (mg/kg)	<388	388 - 477	477 - 570	>570
Respiration (mg/kg)	<24.9	24.9 - 46.0	46.0 - 80.6	>80.6
Soil Protein (g/kg)	<4.1	4.1 - 5.0	5.0 - 6.0	>6.0

Table 3. Soil health value summary of MEDIUM soils.

Variable	Low	Medium	High	Very High
Organic Matter (%)	<1.7	1.7 - 2.0	2.0 - 2.5	>2.5
Soil Organic Carbon (%)	<1.4	1.4 - 1.6	1.6 - 1.9	>1.9
Permanganate Oxidizable Carbon (mg/kg)	<384	384 - 455	455 - 566	>566
Respiration (mg/kg)	<32.5	32.5 - 44.5	44.5 - 62.3	>62.3
Soil Protein (g/kg)	<3.8	3.8 - 4.3	4.3 - 5.0	>5.0

Table 4. Soil health value summary of FINE soils.

Variable	Low	Medium	High	Very High
Organic Matter (%)	<2.2	2.2 - 2.6	2.6 - 3.2	>3.2
Soil Organic Carbon (%)	<1.9	1.9 - 2.2	2.2 - 2.5	>2.5
Permanganate Oxidizable Carbon (mg/kg)	<509	509 - 599	599 - 702	>702
Respiration (mg/kg)	<31.1	31.1 - 46.5	46.5 - 59.1	>59.1
Soil Protein (g/kg)	<4.1	4.1 - 4.7	4.7 - 5.5	>5.5

Classifying By Cation Exchange Capacity

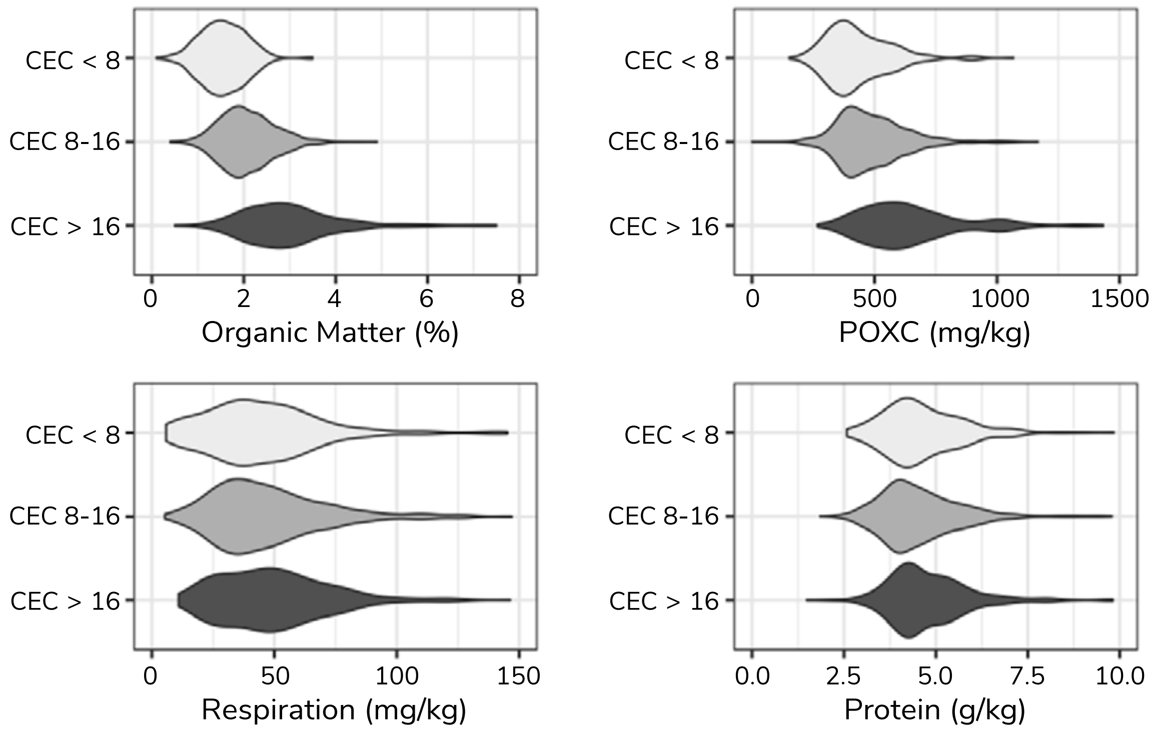


Figure 5. Soil organic matter pool distributions by CEC groupings.

Table 5. Soil health value summary of soil with CECs less than 8 meq/100g (n=392).

Variable	Low	Medium	High	Very High
Organic Matter (%)	<1.2	1.2 - 1.6	1.6 - 2.0	>2.0
Soil Organic Carbon (%)	<1.2	1.2 - 1.4	1.4 - 1.6	>1.6
Permanganate Oxidizable Carbon (mg/kg)	<347	347 - 408	408 - 517	>517
Respiration (mg/kg)	<28.3	28.3 - 42.0	42.0 - 59.1	>59.1
Soil Protein (g/kg)	<3.9	3.9 - 4.4	4.4 - 5.3	>5.3

Table 6. Soil health value summary of soil with CECs between 8 - 16 meq/100g (n=1566).

Variable	Low	Medium	High	Very High
Organic Matter (%)	<1.7	1.7 - 2.0	2.0 - 2.5	>2.5
Soil Organic Carbon (%)	<1.4	1.4 - 1.6	1.6 - 1.9	>1.9
Permanganate Oxidizable Carbon (mg/kg)	<384	384 - 455	455 - 566	>566
Respiration (mg/kg)	<32.5	32.5 - 44.5	44.5 - 62.3	>62.3
Soil Protein (g/kg)	<3.8	3.8 - 4.3	4.3 - 5.0	>5.0

Table 7. Soil health value summary of soil with CECs greater than 16 meq/100g (n=502).

Variable	Low	Medium	High	Very High
Organic Matter (%)	<2.2	2.2 - 2.6	2.6 - 3.2	>3.2
Soil Organic Carbon (%)	<1.9	1.9 - 2.2	2.2 - 2.5	>2.5
Permanganate Oxidizable Carbon (mg/kg)	<509	509 - 599	599 - 702	>702
Respiration (mg/kg)	<31.1	31.1 - 46.5	46.5 - 59.1	>59.1
Soil Protein (g/kg)	<4.1	4.1 - 4.7	4.7 - 5.5	>5.5

CONCLUSIONS AND NEXT STEPS

Soil health testing is an emerging practice that is still in development. There are many more questions than answers at this point, but scientists, agronomists, farmers, and others are working together to make sense of the variation observed and the measurements that can be used to effectively track improvement in soil health.

Here we provided a baseline of soil health values for Ohio soils. Drawing on over 2,400 soil samples from 75 counties, we have documented what 'typical' values are in Ohio. The next step is using this information to understand how management impacts soil health, and ultimately how these values can inform future management and actionable decisions.

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Data Source Details

- Fertilizer recommendations trials in field crops (Culman led, Ohio Soybean Council funded, 2014-2018; n = 655)
- Nitrogen rate trials in corn and wheat (Culman led, Ohio Corn and Wheat funded; 2015-2018; n = 166)
- Evaluating Soil Protein as a New Soil Health Indicator, funding Year: 2017.
- Active organic matter soil health testing (Culman led, Ceres Trust funded, 2014-2016; n = 161)
- Hop fertility project (Culman led, USDA-North Central Sustainable Agriculture Research and Education; NC-SARE, 2019-2021; n = 135)
- Step-Up-Soybean (Laura Lindsey led, Ohio Soybean Council funded, 2014-2015; n = 145)
- eFields Soil Health (Culman led, Ohio Soybean Council funded, 2020-2021; n = 636)
- Organic corn farmer survey (Doug Jackson-Smith led, USDA-Organic Agriculture Research and Extension Initiative; OREI, 2018; n = 208)
- Soil health and climate change (Christine Sprunger led, Initiative for Food and Agricultural Transformations funded, 2019-2020; n = 94)
- Tomato soil health (Culman led, MidAmerica Food Processors Association funded, 2017-2018; n = 110)
- Ohio pipeline project (Culman led, Kinder Morgan funded, 2020-2021; n = 144)

References

Culman, S., Fulford, A., Camberato, J., Stienke, K. (2020). *Tri-state fertilizer recommendations for corn, soybeans, wheat, and alfalfa.* (Bulletin 974). Columbus, OH: The Ohio State University.

Deiss, L., Culman, S.W., Demyan, M.S. (2020a) Grinding and sample replication often improves mid-DRIFTS predictions of soil properties. *Soil Science Society of America Journal 84*, 914–929.

Deiss, L., Margenot, A.J., Culman, S.W., Demyan, M.S. (2020b) Optimizing acquisition parameters in diffuse reflectance infrared Fourier transform spectroscopy of soils. *Soil Science Society of America Journal 84*, 930–948.

NCERA-13. (2015). Recommended chemical soil test for the North Central region. (Vol. no. 221). Columbia, MO: University of Missouri.

Soil Survey Division Staff. 1993. Examination and description of soils. Soil Survey Manual. Soil Conservation Service. United States Department of Agriculture Handbook 18. USDA-NRCS. Washington, D.C.

Cornell Soil Health Manual: https://soilhealth.cals.cornell.edu/manual/

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