**Physical Soil Health Indicators**
Physical soil health indicators are soil characteristics that can be measured and observed to assess the soil's physical condition. Optimal soil physical conditions reduce limitations to root growth, improve water infiltration and aeration, decrease soil compaction, and increase water storage capacity. Optimal conditions and physical indicators are also linked to soil functions (Figure 1).

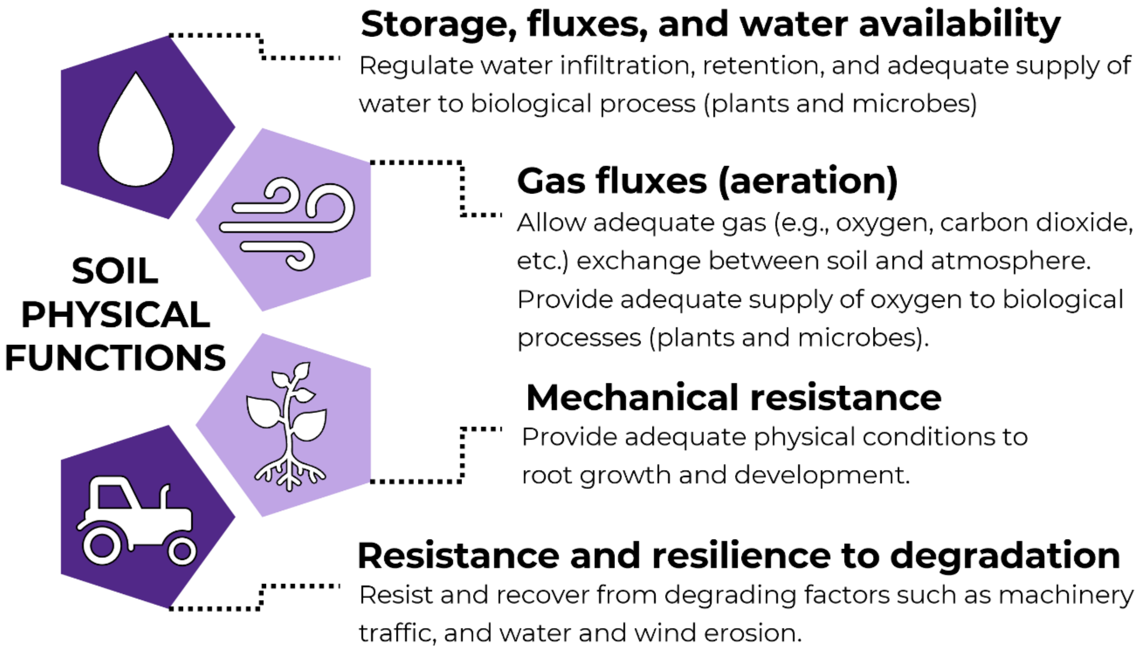


Figure 1. Physical functions soils perform.

Overall, soil with good physical health has a good structure that allows for water and airflow, resists erosion and compaction, permits root growth, and provides habit for soil microbes. Soil structure is the composition of silt, sand, and clay that build soil blocks. The arrangement of these soil particles, as well as the combination of particles, roots, fungi hyphae, and other compounds (e.g., sugars, proteins, etc.) released by microbes, builds soil aggregates, which correspond to the soil structure. The lack of crop diversity and intensively tilled soils can worsen soil physical health. Poor soil physical health can reduce crop yield and increase soil erosion and water runoff. Minimal disturbance (i.e., no-tillage) and plants with robust root systems are key for building aggregates and improving soil structure.

There are several indicators for evaluating soil physical health. Among the most suggested, we can include aggregate stability, water infiltration rate, bulk density, soil penetration resistance, and visual evaluation of soil structure. Soil texture should not be used as a soil health indicator due to its inherent nature and absence of response to soil and plant management. However, texture is an important component of soil characteristics that should drive soil and plant management decisions.

<u>AGGREGATE STABILITY</u>
Soil aggregates can be divided into many classes. The most common classification is macroaggregates (>10 thousand of an inch) and microaggregates (<10 thousand of an

inch). Microaggregates are formed by the agglomeration of soil particles (silt and clay), soil organic matter, organic compounds such as proteins and sugars, small fine roots, and fungi hyphae. Macroaggregates are formed by the further union of microaggregates out of root and fungi hyphae work. Macroaggregates are directly affected by soil management, mainly tillage systems that break out aggregates and release protected soil organic carbon and nitrogen that will be lost and consumed by soil microbes. Several techniques test aggregate stability, including raindrop impact, dry sieving, and wet sieving. Water-stable aggregates by wet sieving is the standard method and should be recommended. This method is characterized by submerging air-dried aggregates in water and measuring the size of the remaining aggregates after shaking. Aggregate stability methods may vary in sample preparation, sieve sizes, sieving time, and water emersion time. A simple on-farm method for measuring aggregate stability is the slaking test. Slaking is the process of suddenly emerging aggregates in water and observing how strong aggregates are to the stress caused by rapid water uptake. Aggregates from soils under no-tillage and cover crops should resist more to the slaking process.

## VISUAL EVALUATION OF SOIL STRUCTURE

Visual evaluation of soil structure (VESS) is used to assess soil structure. It provides a simple framework that uses a qualitative approach to evaluate the physical characteristics of soil structure, including the size, shape, orientation, and distribution of soil aggregates. It requires only a shovel to extract a block of soil and can be done in about 10 minutes with a bit of practice. The VESS evaluation can be used in a variety of settings, including agricultural fields, gardens, and other areas where soil management is a concern.

## WATER INFILTRATION

The water infiltration test is a method used to measure how long it takes to water infiltrate into the soil. The test typically involves the application of water to a soil surface at a constant rate and measuring the depth of water in the soil over time. The test provides information on the permeability of the soil, which is an important soil property that affects the distribution and availability of water in the soil profile. The data obtained from the test can be used to calculate the infiltration rate. This information can be used to evaluate the potential for soil erosion and runoff and the effectiveness of conservation practices such as no-tillage and cover cropping.

## BULK DENSITY

Bulk density measures the mass of soil per unit volume. This indicator provides information on soil compaction, which can affect water-holding capacity and root growth. It is important to note that bulk density can vary within a soil profile and can be impacted by factors such as soil texture and tillage system. A high bulk density can indicate soil compaction and reduced porosity, while a low bulk density can indicate low soil compaction and high porosity. A recently tilled soil may have a low bulk density due to recent disturbance. However, this low bulk density is temporary and will increase over time due to a fragile soil structure. On the other hand, a no-till soil may have a higher bulk density but is stable over time due to its more robust structure.

## SOIL PENETRATION RESISTANCE

Soil penetration resistance is the force required to penetrate the soil with a cone connected to a rod pushed vertically downward. A load cell with compression load type is typically used to measure force during penetration. Some penetrometers are equipped with a sensor to measure the distance as the cone penetrates. With that, resistance at different depths can be obtained. Penetrometers are helpful tools as they can identify compacted areas with minimal energy. Crops root growth is reduced when the soil strength is about 1500 kPa (217 PSI), whereas root growth of several crops breaks when the soil strength is about 2500 kPa (362 PSI). Like bulk density, soil penetration resistance has to be used with caution since it is affected by soil texture and moisture content. Resistance to penetration tests should always be performed when soil is at field capacity, which usually occurs two to three days after a rain or irrigation event.

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