Nebraska Soil Science Curriculum

Soil Bulk Density

Approximately 135 minutes

Content and lab derived from the USDA-NRCS Guides for Educators. Please see the Guides for additional helpful pictures and diagrams.

Objectives

By the end of the lesson, students will know or be able to:

- Define: ammonification, available water holding capacity, nitrification, bulk density, denitrification, respiration, soil porosity, soil water filled pore space, soil water content, gravimetric, volumetric water content
- List and explain factors that affect soil bulk density
- List and describe soil bulk density management processes
- Measure soil bulk density interpret data

Materials

- Sponge
- Pumice stone
- Penny
- Balloon
- Fishing sinker
- Marble
- Terms and definitions
- Laboratory supplies (see Lab Guided Notes)

Preparatory Work

- Secure a location from which to drive a soil sample

Enroll the Participants – approximately 4 minutes

Show students the following items in comparison and ask students which item is most dense within each pair.

A sponge and a penny
A pumice stone and a fishing sinker
A balloon and a marble

Facilitate a discussion with students to ask them what is meant by "dense" and to define "density."

Preview with students that the density of soil helps us indicate the soil's compaction and health.

Provide the Experience – Soil Bulk Density Key Terms – approximately 5 minutes

Provide 10 students each with a key term and 10 other students each with a definition associated with a key term. Instruct students to locate their matching partner.

Label the Information – approximately 10 minutes

Instruct students to share their terms and definitions with the class.

Ammonification: occurs in the nitrogen cycle when soil organisms decompose organic-nitrogen converting it to ammonia.

Available Water Holding Capacity: Soil moisture available for crop growth; also defined as the difference between field capacity and wilting point, typically shown in inches/foot.

Nitrification: Occurs in the nitrogen cycle when soil organisms convert ammonia and ammonium into nitrite and next to nitrate-nitrogen which is available to plants.

Bulk Density: Weight of dry soil per unit of volume, more compacted soil with less pore space will have a higher bulk density.

Denitrification: Conversion and loss of nitrate nitrogen as nitrogen gases when soil becomes saturated with water.

Respiration: Carbon dioxide release from soil from several sources (decomposition of organic matter by soil microbes and respiration from roots)

Soil Porosity: Percent of total soil volume made up of pore space.

Soil Water Filled Pore Space: Percent of pore space filled with water.

Soil Water Content, Gravimetric: Weight of soil water per unit of dry soil weight.

Volumetric Water Content: Amount (weight or volume) of water in soil core by volume.

Demonstrate the Relevance – approximately 7 minutes

Instruct students to talk together and formulate ideas about how soil bulk density affects soil health.

Elicit responses, filling in the following information.

- Bulk density affects the following:
  - Ability of water to infiltrate soil
  - Rooting depth of plants
  - Available water capacity
  - Soil porosity
  - Plant nutrient availability
  - Soil microorganism activity
- Bulk density is a measurement of the weight of dry soil
  - 50% solids (soil particles and organic matter)
  - 50% pore space (filled with air or water)

Provide the Experience – Factors Affecting Bulk Density – approximately 5 minutes

Reiterate that soil bulk density is the weight of dry soil and that the weight is comprised of 50% solids and 50% pore space.

Instruct half of the class to discuss and develop a list of factors that might affect the solids (soil particles and organic matter) found in soil. Instruct the other half of the class to discuss and develop a list of factors that might affect the pore space (space for water or air) found in soil.

Label the Information – approximately 5 minutes

The following factors affect soil bulk density:

- Soil organic matter
- Soil texture
- Density of soil mineral
- Packing arrangement of aggregates

Here are additional key points about bulk density:

- Presence and amount of rock fragment, soil depth and soil texture affect the water capacity of soil
- Loose, well-aggregated, porous, high organic matter soils have a lower bulk density
- Sandy soils have a higher bulk density because of less pore space

Demonstrate the Relevance – approximately 5 minutes

Ask students the following questions:

Based on what you know, what happens to soil bulk density as soil depth increases?

Bulk density increases with soil depth because subsurface layers are more compacted.

What happens to bulk density when fields or gardens are tilled?

Surface bulk density temporarily decreases because of the soil particles being broken up, but the layers below the surface become more compact, increasing bulk density.

How does a higher bulk density impact the ability of roots to support the plant?

The higher the bulk density, the more compact the soil is and the less pore space exists. Higher bulk density makes it difficult for roots to obtain the water and nutrients they need, as well as to grow deep enough to anchor the plant.

Provide the Experience – Bulk Density Management – approximately 3 minutes

Ask students how they believe bulk density could possibly be lowered.

Label the Information – approximately 7 minutes

Bulk Density Management Practices

- Increase soil organic matter
  - Use no till
  - Use cover crops
  - Use solid manure or apply compost
  - Use high residue crops
- Minimize soil disturbances
  - Avoid equipment operation on wet soil
  - Use designated roads or rows for equipment transportation
- Decrease compaction
  - Reduce the number of trips across the field with equipment
  - Reduce the amount of time livestock are permitted to be on the soil
- Use multi-crop systems
  - Plant crops with a variety of rooting depths

Demonstrate the Relevance – approximately 5 minutes

Facilitate a discussion with students that is relevant to them; how does bulk density affect a garden's ability to perform? What steps could be taken to decrease soil bulk density in a garden? In a field?

Provide the Experience – Measure and Interpret Bulk Density – approximately 90 minutes

Introduce each of the laboratory supplies to the students and review the laboratory processes and procedures with the class. See the guided notes lab for information. If possible, play the NRCS lab instructions video for students.

Students engage in the lab activity.

Label the Information – time varies

Students record information and answer lab questions.

Demonstrate the Relevance – time varies

Discuss with students how bulk density affects the ability of farmers to produce food for consumers.

Review the Content – 7 minutes

Instruct students to work in small groups to create a poster that they can share with other students about soil bulk density facts.

Guided Notes: Soil Bulk Density

Ammonification:

Available Water Holding Capacity:

Nitrification:

Bulk Density:

Denitrification:

Respiration:

Soil Porosity:

Soil Water Filled Pore Space:

Soil Water Content, Gravimetric:

Volumetric Water Content:

Factors that Affect Soil Bulk Density

How do bulk density, moisture and aeration relate?

How do we manage bulk density?

Guided Notes: Soil Bulk Density Laboratory

Soil Bulk Density Scenario

Catherine and Ray want to plant a garden in their new yard, but the best location for the garden doesn't even grow grass currently. The ground is very hard, and they think the bulk density of the soil might be too high for good root penetration. They are hopeful that they can improve the bulk density by planting a variety of plants over the next several years.

Laboratory Supplies

- 3-inch diameter aluminum ring
- Wood block or plastic insertion cap
- Rubber mallet or weight
- Folding trowel
- Flat-bladed knife
- Sealable bags and marker pen
- Scale (1 gram precision)
- 1/8 cup (29.5 mL) measuring scoop
- Ceramic coffee cup
- 18-inch metal rod, probe or space (to check for compaction zone)
- Access to a microwave oven

Laboratory Steps

Bulk density can be measured at the soil surface and/or compacted tillage zone. Bulk density samples should be taken in the same location as infiltration and respiration tests. It may be possible to use the infiltration test sample. For sticky clay soils, a little penetrating oil applied to the ring makes it easier to remove the soil.

Step-by-Step Procedure

1. Carefully clear all residue and then drive the ring to a depth of three inches with a small mallet or weight and a block of wood or plastic cap.
2. Remove the ring by cutting around the outside edge with a small 4-inch serrated butter knife and using the small folding trowel underneath of it.
3. Carefully lift the ring out, preventing loss of soil by holding the trowel under it.
4. Remove excess soil from the bottom of the cylinder with serrated butter knife.
5. Place the sample in a plastic sealable bag and label it.
6. Weigh the sample in the bag and record its weight in Table 1.
7. Weigh an identical clean, empty plastic bag and record its weight in Table 1.
8. Weigh an empty microwavable cup to be used in step 9 and record its weight in Table 1.
9. Either extract a subsample or dry and weigh the entire sample to determine water content and dry soil weight:
    a. Mix the sample thoroughly in the bag by kneading it with your fingers.
    b. Take a 1/8 cup level scoop of loose soil (not packed down) from the plastic bag and place it in the cup weighted in step 8. Use more than one scoop to increase accuracy of the measurement.
10. Weigh the moist subsample in the cup before drying it and record the weight in Table 1.
11. Place the cup containing the subsample in a microwave and dry the sample for two or more four-minute cycles at medium power.
12. To determine if soil is dry, weigh the subsample in a cup after each 4-minute cycle. When the weight no longer changes after a drying cycle, it is dry.
13. Record its weight in Table 1.

Interpretations

Complete Table 1 for bulk density and soil water content determination and compare the results to the same soil texture listed in Table 2 to determine relative restrictions to root growth or compaction concerns. Complete Tables 3, 4 and 5 for soil water and porosity determination.

Table 1. Bulk density and soil water content (core method). Refer to calculations below for details.

Sample Site	(a) Weight of field moist soil + sample bag (grams)	(b) Weight of sample bag (grams)	(c) Weight of cup (grams)	(d) Weight of cup + moist soil (grams)	(e) Weight of moist soil (grams) (d-c)	(f) Weight of dry soil + cup (grams)	(g) Dry weight of soil (grams) (f-c)	(h) Soil water content (grams/gram) (d-c)/(g)	(i) Soil bulk density (g/cm^3)

Volume of Soil Core (cm^3) (refer to Figure 11)

πr^2 x height

Example 1 (refer to Figure 11)

3.14 x $(3.66\ cm)^2$ x (7.62 cm) = **321 cm^3**

Soil Water Content Using a Subsample (g/g)

$$\frac{\text{weight of moist soil - weight of oven dry soil}}{\text{Weight of oven dry soil}}$$

Example 1 (e - g)/(g)

$\frac{(34g - 27g)}{27g}$ = **0.259 g of water/g of soil**

Calculating the Dry Weight of the Bulk Sample Based on Soil Water Content of Subsample (grams)

$$\text{Dry wt of soil bulk sample} = \frac{[\text{Wt of field moist soil + bag (grams) - Wt of bag (grams)}]}{[1 + \text{Soil Water content (g/g)}]}$$

Example 1: dry wt of bulk sample = [(a - b)/(1 + h)] = $\frac{(490\ g - 5\ g)}{(1 + .259)}$ = 385 g

<u>Bulk Density Calculation</u> (g/cm^3)

Bulk Density = Dry wt of bulk sample ÷ volume of soil core

Example 1: bulk density = 385g ÷ 321 cm^3 = **1.20 g/cm^3**

Table 2. General relationship of soil bulk density to root growth based on soil texture.

Soil Texture	Ideal bulk densities for plant growth (grams/cm^3)	Bulk densities that affect root growth (grams/cm^3)	Bulk densities that restrict root growth (grams/cm^3)
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.40	1.60	> 1.75
Silt loams, silty clay loams	< 1.40	1.55	> 1.65
Sandy clays, silty clays, clay loams	< 1.10	1.49	> 1.58
Clays (> 45% clay)	< 1.10	1.39	> 1.47

Soil Water Content and Porosity Calculations

Table 3. Soil water content.

Sample Site	Soil Water Content (by Wt) (g/g) (from h in Table 2)	Bulk density (g/cm^3) from Table 2	* Volumetric water content (g/cm^3)	** Inches of water/ft. of soil depth
Example 1	0.259	1.2 g/cm^3	0.3108 g/cm^3	3.7"/ft

* Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)
** Inches of water/ft. of soil depth = volumetric water content x 12"/ft

Table 4. Soil porosity (%).

Sample Site	**Bulk Density ($grams/cm^3$) from Table 2**	**Calculation 1 - (soil bulk density / 2.65)**	*** Soil porosity (%)**
Example 1	1.2grams/cm^3	1 - (1.2/2.65)	0.547 or 54.7%

* Soil porosity (%) = 1 - (soil bulk density / 2.65). The default value of 2.65 is used as a rule of thumb based on the average bulk density of rock with no pore space.

Table 5. Soil water filled pore space (%).

Sample Site	**Volumetric water content ($grams/cm^3$) from Table 3**	**Soil porosity from Table 4**	**Volumetric Water Content / Soil porosity x 100**	*** Soil Water-Filled Pore Space**
Ex. 1	0.3108 grams/cm3	0.547	0.3108 g/cm^3 / .547 x 100	.568 or 56.8%

* Soil water-filled pore space (%) = (volumetric water content / soil porosity) x 100

How did the soil bulk density results differ from what you expected?

Compare the bulk density results to the values found in Table 2 for the same soil texture of your sample. Are bulk density levels ideal based on the soil texture? Why or why not?

Ammonification

occurs in the nitrogen cycle when soil organisms decompose organic-nitrogen converting it to ammonia.

Available Water Holding Capacity

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