Soil compaction and strength; measurement methods and influences on perennial grass growth.

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Outline

• Definitions
• Limits to plant growth
• Tokunaga’s study; Methods & Results
• Discussion

Source: USDA-NRCS Plant Materials Program
Soil Compaction

• Increasing the soil bulk density, and concomitantly decreasing the soil porosity, by the application of mechanical forces to the soil. (SSSA)
• Commonly expressed as g/cm$^3$ (or lbs/ft$^3$)
Direct measure of soil compaction - Bulk Density (Db)

- The mass of dry soil per unit volume
- <2 mm fraction of soil, no coarse fragments
Soil Strength
Penetration Resistance (PR)

• Capacity of a soil to resist a force without rupture, fragmentation, or flow
• Resistance to penetration by roots
• Affected by several factors, including soil moisture (lubrication)
Limits to plant growth

Root limiting bulk densities…

• Compaction studied most often in agriculture
• Taproot species or C₄ (warm-season) grasses
• Root-limiting bulk densities…
  ▫ 1.5 g cm⁻³ fine textures
  ▫ 1.9 g cm⁻³ coarse textures
  ▫ No single critical bulk density apparent in literature
Limits to plant growth, cont.

Root-limiting soil strength…

- 2.5 to 3 MPa (363 to 435 psi)
- 6 to 7 MPa (coarse soils)
- Strength varies with both bulk density and water content – in rangelands it may vary with season.
  e.g., denser and drier = increased strength
Limits to plant growth, cont.

Besides physical root impedance, compaction can lead to…

- Decreased infiltration
- Slower water and gas movement
- Typically the uppermost 10 cm tend to be compacted by grazing animals (compared to deeper seated compaction by heavy equipment, glaciers, etc.)
Tokunaga’s Research Questions (M.S. thesis at HSU)

• How does root and shoot biomass production vary over a range of bulk density and soil strength?

• Is there a threshold bulk density and/or soil strength that limits biomass production of roots and/or shoots?
Study Site

- Nixon Ridge
- Annual vegetation
- Blue wildrye
- Oak woodland
- Grazed
Greenhouse Methods

• Surface soil collected from Nixon Ridge and sieved to <2 mm

• 3 bulk densities
  ▫ “loose” = 1.00 g cm\(^{-3}\) (gopher mounds and/or high litter content)
  ▫ “medium” = 1.25 g cm\(^{-3}\)
  ▫ “dense” = 1.55 g cm\(^{-3}\) (previous studies)
  ▫ Compacted using ASTM protocols
Greenhouse Methods cont.

• 3 water potentials
  ▫ “wet” = -33 kPa (field capacity)
  ▫ “moist” = -500 kPa (moderate water stress)
  ▫ “dry” = -1500 kPa (permanent wilting point)
  ▫ Maintained 3 days a week
Greenhouse set-up

about 4 months growth of Blue Wildrye (perennial, cool season),
rotated and watered 3x week, randomized weekly
n=25 for each Db/moisture combination
Dense          Medium          Loose

Dry

Moist

Wet
Greenhouse Variables

- Shoot biomass → clipped and dried
- Root biomass → washed and dried
- Soil strength → penetrometer
- Hydraulic press
- Root depth → split core
RESULTS

• Different letters (a, b, c) indicate significant differences at $p=0.05$ using Analysis of Variance
Shoot Biomass

$n = 25$

Bulk density (g cm$^{-3}$)

- 1500 kPa
- 500 kPa
- 33 kPa

Shoot biomass production (g)
Root Biomass

n = 9

Bulk density (g cm\(^{-3}\))

Root biomass production (g)

-1500 kPa

-500 kPa

-33 kPa

- 1.00
- 1.25
- 1.55

abc
dbcd
cd
cd
Roots and Shoots

Biomass production (g)

Treatment

- loose-dry
- loose-moist
- loose-wet
- med-dry
- med-moist
- med-wet
- dense-dry
- dense-moist
- dense-wet

Roots and Shoots
Maximum Root Depth

Bulk density (g cm$^{-3}$)

<table>
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<tr>
<th>Bulk density (g cm$^{-3}$)</th>
<th>Maximum root depth (cm)</th>
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<td>1.25</td>
<td>moist-500 kPa</td>
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<tr>
<td>1.55</td>
<td>wet-33 kPa</td>
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</table>

- dry-1500 kPa
- moist-500 kPa
- wet-33 kPa
PR—Penetrometer

n = 21

Penetration resistance (MPa) vs. Depth (in) for different soil conditions:
- medium-dry
- medium-moist
- medium-wet
- loose-dry
- loose-moist
- loose-wet
PR—Hydraulic Press

\[ n = 4 \]
Discussion
Soil Strength Methods

Penetration resistance (MPa)

- medium-dry
- medium-moist
- medium-wet
- loose-dry
- loose-moist
- loose-wet

Penetrometer
Hydraulic press
## PR and Roots—Penetrometer

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<th>Med-wet</th>
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## PR and Roots—Hydraulic Press

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<th>Depth (in)</th>
<th>Highest root biomass</th>
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Summary—Roots

• Lower root biomass production:
  ▫ Higher bulk density
  ▫ Higher soil strength
  ▫ Shallower root depth

• Higher root biomass production:
  ▫ Lower water stress
  ▫ Can have higher soil strength
Summary—Roots

• Roots penetration and biomass production can potentially be high over a wide range of soil strength above 2.5 MPa
# PR and Shoots—Penetrometer

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<th>Med-wet</th>
<th>Med-moist</th>
<th>Loose-wet</th>
<th>Loose-moist</th>
<th>Dense-wet</th>
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- Lowest shoot biomass
- Highest shoot biomass
# PR and Shoots—Hydraulic Press

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Summary—Shoots

• Higher shoot biomass production:
  ▫ Lower water stress
  ▫ Deeper root depth
  ▫ Can have higher soil strength

• Similar shoot production occurs under contrasting belowground conditions
Field Relevance and Conclusions

General trend in biomass production:

• Increasing bulk density and soil strength decreases biomass production and root penetration

• High production and deep root penetration can occur in soils that exceed 2.5 MPa

• Effects possibly moderated by water availability
Field Relevance and Conclusions

• Is there a threshold bulk density or soil strength?
• Similar production can occur across a range of bulk densities.
• A wide range of soil strength data were obtained using different instruments - provides a range of soil strengths associated with lower production.
Field Relevance and Conclusions

• Physical difficulty in obtaining quantitative data on very compacted and strong soils (and these didn’t have rocks!)

• Penetrometer
  ▫ Useful under agricultural conditions
  ▫ Less useful on rangeland conditions

• Hydraulic press
  ▫ For dense and strong soils
  ▫ Of little field value

• Wide range of measurements
Final Thoughts

• Tate et al. (2004) REM 57(4):411-417 took 1,489 bulk density samples at SJER to tease out the effects of grazing management, RDM and other site factors.

• The interactions of bulk density, strength and moisture status are important for annual plants that ‘regerminate’ and grow annually.
Final Thoughts

These same interactions influence perennial grasses differently…

• High Db and strength can limit soil volume exploited by roots for water and nutrients (critical for year-to-year survival).
• As long as water is available, grass roots penetrate beyond what has been recorded for many agricultural crops.
• High bulk density may be more important in terms of water infiltration and deep percolation compared to physical impedance to root growth in field settings.