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# Soil Water and Resiliency

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*“Use the ‘adaptive management’ approach, acknowledging that because of uncertainty and unpredictability, plans have to be continually adjusted using results from monitoring”.*  
J. Thorpe, 2012

## Relevant Factsheets:

Forage Fact #95:  
Soil Quality Field Kit Part I  
Forage Fact #96:  
Soil Quality Field Kit Part II  
Forage Fact #106:  
Soil Quality For Resilience

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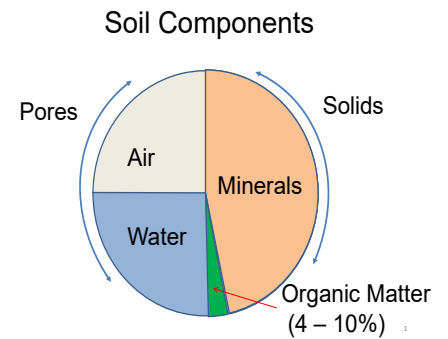
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## Context For This Factsheet

This forage fact is part of the project “Innovative Management Practices for Resiliency”. The project works with farmers and ranchers to identify and evaluate nutrient or cropping management practices that will be more resilient to climate change extremes.

Water is critical to forage and beef production. This factsheet answers questions about soil water. It then provides suggestions about how to manage soil water.



## Fundamentals (FAQs)

### Why do plants need water?

Simply put, to maintain pressure on cell walls for growth and for cooling by evaporation. To grow, plants must let carbon dioxide in to manufacture tissues. Openings (stomata) in leaves allow carbon dioxide to enter, but also allow water vapor to escape. With inadequate water, stomata close and growth stops.

### How do plants get water out of soil?

Fine roots (< 0.1 mm diameter) & root hairs absorb water from soil pores. Grasses may have  $\frac{1}{4}$  to  $\frac{1}{2}$  of their mass as roots. Root lengths are hundreds of meters per gram of root.

### Where is water in soil?

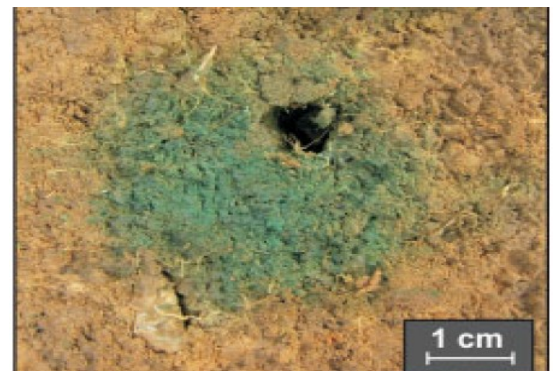
Water is stored in the space between solid particles that is shared with soil air - called pores. Ideally about 60% of soil volume is pores, although 40 to 50% is common.

### What lets water into soil?

Large pores do. Water moves quickly through large empty pores. Old root channels, cracks, earthworm burrows, and large aggregates create large pores.

### What keeps water in soil?

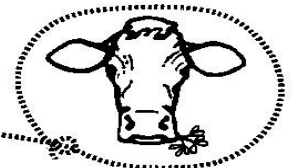
Small pores do. Water adheres to soil pore walls. Soil pores vary from > 5 mm to < 0.0001 mm in diameter. Gravity pulls water from pores > 0.01 mm diameter. As pore diameter decreases, increasing force is needed to pull water from soil pores.



Dye movement with water outward from an earthworm burrow in Ontario.

Source: Cey, E. E. & Rudolph, D. L. 2009.  
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Peace River Forage Association  
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Saturated field with water on the surface (*above*).

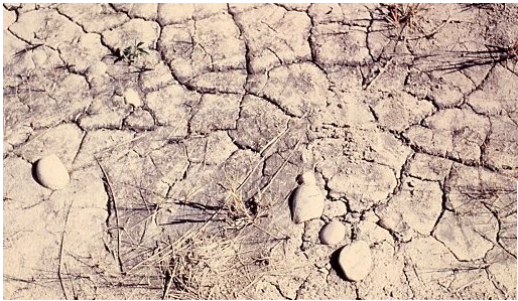
## Classification & Measurement

### Water at Saturated Soil Conditions

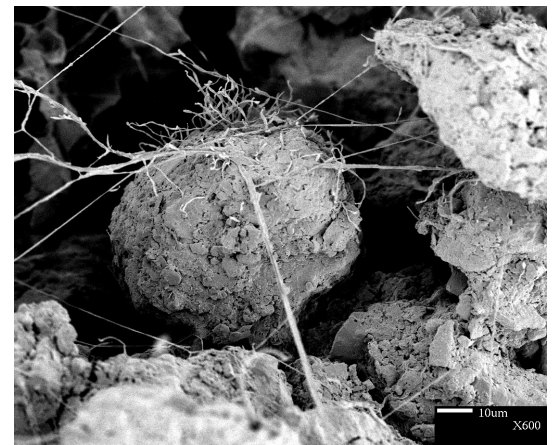
All soil pores are full of water, and water occupies about 40 - 60% of soil volume.

Animal or vehicle traffic on saturated soils causes puddling, loss of soil structure (aggregation) and impedes future water infiltration.

Saturated soils have no volume available for air, so oxygen is quickly depleted. Anaerobic processes start. One such process is denitrification, which converts nitrate ( $\text{NO}_3^-$ ) to nitrite ( $\text{NO}_2^-$ ), then to nitrous oxide ( $\text{N}_2\text{O}$ ) and finally to nitrogen gas ( $\text{N}_2$ ). Both  $\text{N}_2\text{O}$  and  $\text{N}_2$  escape from the soil and are unavailable for forage production. Nitrous oxide from agriculture is a significant source of greenhouse gas.



Crusted soil after puddling of exposed surface of soil with poor infiltration (*photo to left*).



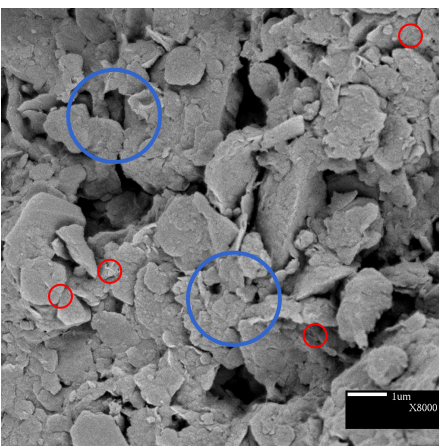
Microscope image of soil aggregates and pores. The aggregate in the middle is about 0.07 mm across. Pores around it vary from 0.02 to 0.07 mm in size.

### Field Capacity

Following a rain, gravity moves water downward for about 24 to 48 hours. The water may carry some soluble plant nutrients such as nitrate and sulfate to deeper soil depths or even beyond the root zone.

The soil water content after the drainage described above is called **Field Capacity** (FC). Optimum conditions for aerobic soil biological activity require a balance between adequate water for solute transport and for plant uptake, on one hand; and adequate air to provide oxygen for respiration, on the other. Ideally this occurs when about 60% of soil pores are filled with water. FC is close to such conditions.

Pores within the aggregate in the center, which is about 0.07 mm in diameter, would hold water at FC.



The larger pores (*in blue circles*) in the microscope image below hold no water at PWP. The smaller pores (*in red circles*) would retain water.

### Permanent Wilting Point

As soil dries from field capacity, water becomes increasingly difficult for plants to remove. Eventually soil water is held so tightly that plants can't exert enough force to remove it. Plants normally can't exert a force per unit area in excess of about 15 atmospheres (about 220 pounds per sq. inch). This is called the **Permanent Wilting Point** (PWP). At the PWP, water is in soil pores of < 0.0001 mm in diameter. From  $\frac{1}{4}$  to  $\frac{1}{3}$  of soil pore volume may still be occupied by water at the PWP. About half of the original water at FC is unavailable for extraction by plants.

### Available Water Holding Capacity (AWHC)

**Available Water Holding Capacity** (AWHC) is the volume of water between FC and the PWP. This is the soil water that plants can use. It constitutes about half the water that can be held at FC. If soils are recharged to FC for several feet, and if the rooting depth is several feet, then the available water can be considerable. If, however, recharge with water is only a few inches, or doesn't reach FC, then available water is seriously restricted. Available water content can be modified or conserved by some management practices as shown on the next pages.



## Factors Controlling Available Soil Water

### Work With These – You Can't Change Them

Even if these properties can't be changed, you should be aware of them and work with them.

**Precipitation:** Precipitation determines moisture input. Management should conserve moisture in times of low precipitation, on one hand, and accommodate excess water in times of high precipitation on the other. Resiliency requires practices and soil conditions that favor both.

**Capillary Rise:** Capillary rise provides moisture from below. It is important in areas where the water table is within a few feet of the rooting zone. It can provide moisture or if not used for crops it may bring salts to the surface and increase salinity.

**Soil Texture (Sand, Silt, & Clay Content):** Field Capacity (FC) moisture content is shown by the tops of the blue bars in the graph (right) and ranges from 1.5 inch in sand ↓ to about 5.5 inches of water per foot of soil in clay. ↓ Because some moisture is held too tightly for plants to extract, (top of red bars in Graph 1) only a portion of soil moisture is available. Available Water (AW) varies from 0.7 in/ft. in sand ↓ to about 2.1 in/ft. in silty clay loam ↓ (blue bars in Graph 1).

### Things You Can Change

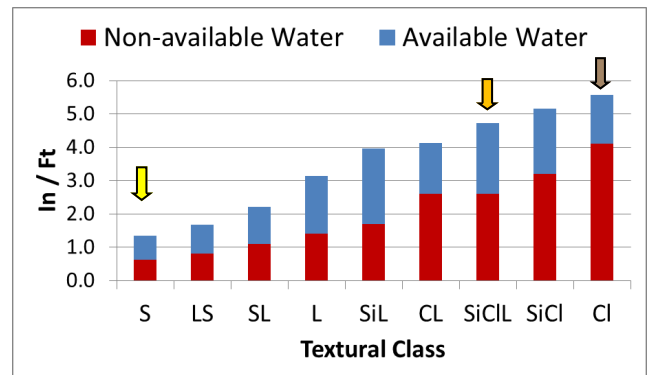
**Snow Retention:** About 186 mm or 35% of the average annual precipitation comes as snow in Ft St John. Retaining it is important. If an additional 30% of snow precipitation could be retained, it could add 55 mm (2 inches) of extra soil water.

**Runoff:** Water that runs off sloping land during heavy rains or spring snow melt is lost for crop production and poses an erosion risk. Runoff may carry nutrients to streams and lakes causing water pollution.

**Infiltration:** Water enters soil best through large pores. Pore size is proportional to the size of the units that create them. Large soil aggregates provide large pores to facilitate water infiltration. Cracks allow flow of water to smaller pores at depth. Micro-aggregates retain water.

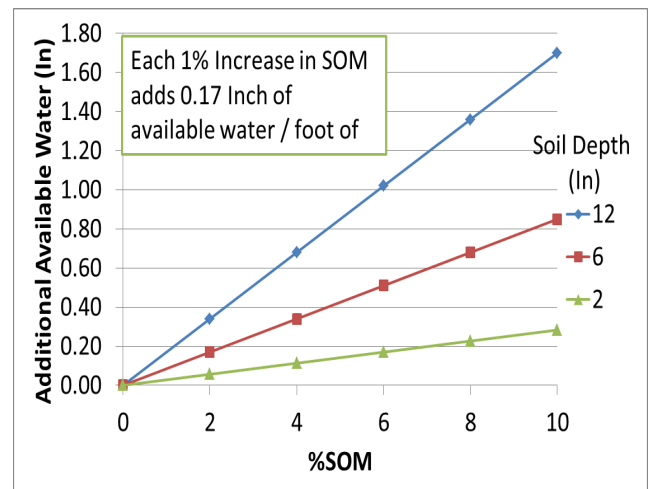
**Soil Organic Matter:** Soil organic matter influences soil water in two ways. First, it increases FC and water retention by about 0.17 inches of water per foot of soil for each 1% organic matter. Second, it stabilizes soil aggregates thereby aiding water infiltration. It is a key soil management variable because it can be managed and it influences so many other properties affecting plant growth. (see Graph 2 at right.)

**Aggregation and Pore Size:** Soil aggregates consist of stable assemblies of mineral and organic constituents. Micro-aggregates (< 0.25 mm) are associations of clay and organic molecules held together by ions with multiple positive charges (e.g.  $\text{Ca}^{+2}$ ,  $\text{Fe}^{+3}$  etc.). Micro-aggregates become joined by microbial exudates (soluble gums or mucilage released from organisms into soil) to form macro-aggregates (> 0.25 mm). Without inputs of plant residues, microbial exudates are depleted, macro-aggregates disintegrate and release micro-aggregates. Micro-aggregates assembled into macro-aggregates provide the ideal mix of large pores to allow water infiltration and micro pores to retain water.



**Graph 1:** Available & Non-available Water

Note: S = Sand; L = Loam; Si = Silt; Cl = Clay. The symbols are used alone or in combination to represent soil textural classes. From equations of Rawls et al. 1982 as reported by Kern, 1995.



**Graph 2:** Available water holding capacity increases as % soil organic matter (% SOM) increases.

**Key messages:**

Each additional 1% soil organic matter increases available water holding capacity (AWHC) by 0.17 inch per foot of soil.

Increasing snow water retention by 30% could add 55 mm (or 2 inches) of extra soil water.



Ron Buchanan increased the AWHC from 0.3 to 0.5 in per ft of soil with 2 yr winter feeding.

**Good Reading:**

Campbell, CA et al. 1992. J Soil & Water Conserv. 47:112-115

Cey, E. E. & Rudolph, D. L. 2009. Hydrol. Process., 23: 1768-1779. doi:10.1002/hyp.7302.

Kern, J. 1995. Soil Sci. Soc Amer. J. 59:1134-1141

Thorpe, J. 2012. Saskatchewan Research Council Publication No. 12855-1E12

Tilman, D. et al. 2006. Nature Vol 441:629-632; doi:10.1038/nature04742

van der Kamp, G. et al. 2003. Comparing the hydrology of grassed & cultivated catchments in semi-arid Canadian Prairies. Hydrol. Process. 17: 559-575

## Managing Soil Water for Climate Extremes

### Managing Soil

**Retain Snow:** especially on high spots by keeping surface roughness and tall plant residues. Based on work in Saskatchewan (Campbell et al., 1992) tall stubble may retain an extra 13 mm (0.5 inch) of snow water and up to 48 mm (1.9 inches) if the soil was extremely dry the previous fall. Practices to increase snow retention also reduce erosion.

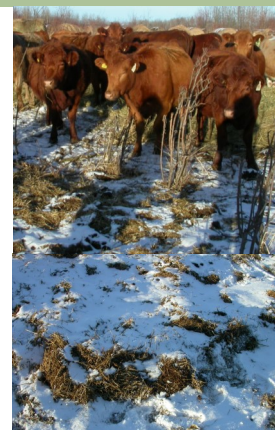
**Optimize Infiltration:** by minimizing runoff. Maintain plant residue cover, macro-aggregates & pore continuity by reducing disturbance such as tillage. Avoid compaction from prolonged vehicle or livestock traffic to maintain a high total pore volume.

**Maintain Soil Aggregates:** by continually adding more plant residues and minimizing disturbance.

**Maintain Surface Residues:** on soil surface to slow water movement, retain water in place, reduce disruption to soil aggregates and enhance water infiltration.

**Maintain Soil Organic Matter:** to enhance aggregation, increase available water holding capacity, reduce soil bulk density and increase pore volume.

**Enhance Soil Animal Activity:** especially earthworms to create channels for water entry by minimizing disturbance and maintaining surface residues.



Gordon Lazinchuk bale grazed to retain snow & surface residues. AWHC was improved 0.1 to 0.5 in per ft of soil in the upper soil layer.



Glenn Hogberg added composted manure to increase soil organic matter. This increased AWHC by 0.4 in per ft of soil (as measured in the upper 5" layer).

Innovative Practice	Managing Soil Strategy	Cooperator	Increase in AWHC
Bale grazing	Maintain soil aggregates & surface residues	Gordon Lazinchuk	0.1 to 0.5 in/ ft soil
Winter feeding	Retain snow & surface residues	Ron Buchanan	0.3 to 0.5 in/ ft soil
Composting manure	Maintain organic matter	Glenn Hogberg	0.4 in/ ft soil

**Selecting Forages to Manage Soil Water:** Forages vary in the quantity of water they use, depth of water extraction and tolerance of drought. Introducing grasses reduces runoff to wetlands mainly by efficient snow trapping and enhanced infiltration (van der Kamp et al, 2003). A mix of forage species may be most desirable. Higher crop diversity favored grassland productivity in Minnesota (Tillman et al, 2006). They concluded that biodiversity favored reliable livestock feed production. A healthy pasture is insurance against weather extremes.

**Compiled by:** Bill McGill, Sandra Burton & Julie Robinson in March 2017.

**With Contributions from:** Ron Buchanan, Rod Strasky, Gordon Lazinchuk, Jodi Kendrew, Fred & Lise Schneider, Glenn Hogberg, Bill Wilson, Serena Black & Darwin Anderson.

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