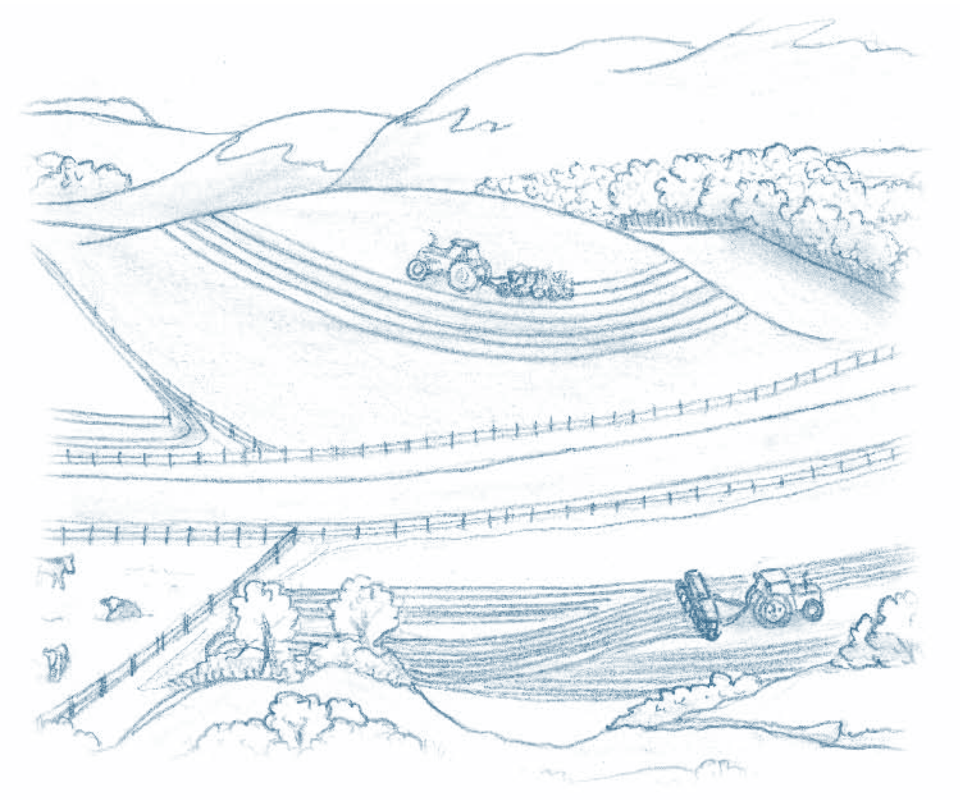
Chapter 8.1

Factors Affecting Runoff Nutrient Losses



learning objectives

- Explain how runoff, soil erosion and nutrient loss are related.
- Identify the factors that influence soil and nutrient erosion losses due to runoff.

Important Terms

Table 8.1.1 Key Terms and Definitions

Term	Definition
Infiltration	Is the process by which water on the ground surface enters the soil.
Fissures	Physical cracks in soil caused by the loss of water or frost action.
Erosive Energy	The ability of flowing water to detach and transport soil particles. The erosive energy of running water depends on its volume and velocity.
Surface Runoff	A term used to describe the flow of water, from rain, snowmelt, or other sources, over the land surface. It is part of the water cycle.
Water Holding Capacity	Describes the total amount of measurable water that can be retained in a soil profile, and held against gravitational pull.

Runoff is that portion of total precipitation (rain and snow) that does not infiltrate into the soil but instead flows over the soil surface. Snowmelt is responsible for more than 80% of runoff that occurs in Alberta. Runoff can transport nutrients from the field reducing the amount of nutrients available to support crop production. Nutrient-enriched runoff also contributes to accelerated eutrophication of surface water bodies, which can decrease water quality (Chapter 2.3).

Soil nutrients are lost through runoff in two main ways:

- Nutrients in soil solution can be lost as dissolved forms in runoff.
- Sediments carried in runoff can transport nutrients associated with soil mineral particles or organic matter complexes.

The application of nutrients, in excess of crop requirements, or at times when the crop is not using nutrients leads to accumulations of nutrients that can be lost to runoff. To minimize nutrient losses in runoff, apply manure and fertilizer at rates and times that coincide with periods of greatest crop uptake.

Aside from altering the rate and timing of nutrient application, it is difficult to design strategies that effectively target dissolved nutrient losses. Many of the practices used to control water erosion can also reduce sediment-bound nutrient losses.

This chapter will look at factors that influence the occurrence and erosive potential of runoff. The two chapters that follow will focus on specific strategies and control measures that target these factors to reduce the risk of nutrient loss in runoff.

Timing, Rate and Form of Precipitation

Precipitation from rainfall and runoff from snowmelt are the driving factors for soil erosion. An understanding of how the timing, intensity and form of precipitation and runoff affect runoff potential will help in the design of strategies to control runoff and water erosion.

Timing and Rate

Timing and rate of precipitation are critical factors affecting runoff. High intensity storms will cause more runoff than low intensity storms. For example, considerable runoff may occur on a site that receives 50 mm of rain in one or two short, severe storms versus if the same volume of rain was to fall on the same site over the course of a week in several intermittent showers.

Likewise, a slow, steady springmelt event is associated with less erosion than a fast springmelt event, which may release a large quantity of water over a short period of time.

The condition of the soil at the time of rainfall or runoff is also important. Wet soils generally have lower infiltration rates than dry soils since pore spaces are already filled with water. In addition, certain types of clay swell upon wetting, which reduces the size and number of pores or small channels in the soil making it more difficult for subsequent precipitation to infiltrate.

The state of the soil at the time of the first major snowfall (i.e., snow remains until the following spring) also has an important influence on the amount and extent of runoff from a site (Figure 8.1.1).

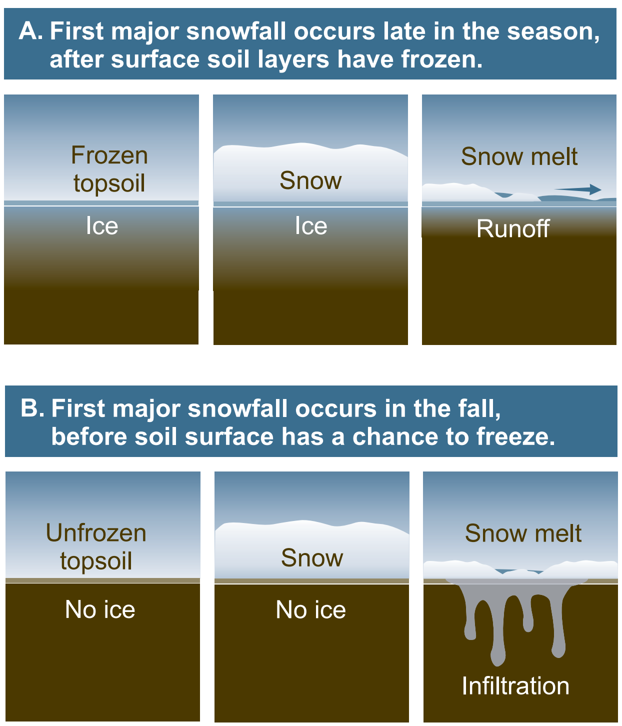


Figure 8.1.1 Effect of Timing of First Major Snowfall on Runoff

In the first scenario (Figure 8.1.1A), the first major snowfall occurs late in the year (e.g., mid to late November) after surface soil layers have frozen. The snow cover insulates the frozen ground resulting in increased runoff during spring thaw since the ground remains largely impermeable. In the second scenario (Figure 8.1.1B), the first major snowfall occurs earlier in the year (e.g., early to mid October). The insulation properties of the snow cover influence the extent to which ice crystals form in the surface layers of the soil. The result can be less runoff during spring thaw since surface soil has greater permeability to infiltration of melt water.

Forms of Precipitation

The majority of Alberta's surface water runoff is generated by snowmelt. Snowmelt runoff usually occurs in the early spring (March to April) as daytime temperatures warm to above zero. The water released from the melting snow is unable to infiltrate into partially or completely frozen soil resulting in surface water flow or runoff. This increases the risk of snowmelt water flowing from fields into surface water bodies compared to runoff from rainfall.

Water infiltration dynamics during snowmelt into thawing soils are complex. An important factor is the moisture content of the soil at the time of freezing. Soils that have drained prior to freezing allow greater water infiltration. Soils that were saturated at the time of freezing will have formed ice crystals, which effectively plug soil pores. Soil structure can be degraded in frozen saturated soils as aggregates break down from the force exerted by expanding water as it freezes. The resulting degradation of soil structure results in slower drainage and less water infiltration.

more info

To learn more about RUSLE and application to Canadian conditions, consult the following online document from Agriculture and Agri-Food Canada (AAFC):

Wall, G.E., Coote, D.R., Pringle, E.A. and Shelton, I.J. (Eds). 1997. Revised Universal Soil Loss Equation for Application in Canada: A Handbook for Estimating Soil Loss from Water Erosion in Canada. http://res2.agr.ca/CRECO/pubs/pdf/rusle_e.pdf

Rainfall can be a source of runoff and erosion. The potential for rainfall to create runoff depends on soil conditions (e.g., frozen versus thawed), soil type, rainfall intensity and volume, slope, ground cover, the soil's water holding capacity and the soil's structural integrity (e.g., compacted or not). Some of the most erosive events in Alberta have occurred due to large rainfall events that have overwhelmed the capacity of existing drainage paths, waterways and soil to absorb and hold water and maintain structure.

The Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) lists the main factors that contribute to soil erosion. An understanding of these factors and how they affect soil erosion helps with the design of sound strategies to control runoff. The Universal Soil Loss Equation (USLE) was developed in the United States in the mid 1960's, and was revised (RUSLE) for Canadian conditions in the 1990's to estimate soil losses due to surface runoff:

$$A = R \times K \times L \times S \times C \times P$$

Where,

A = soil erosion loss in tonnes/hectares

R = rainfall factor

K = soil erodibility factor

L = length of slope factor

S = slope factor

C = cropping system/ground cover factor

P = management practices factor

Soil Properties

Soil properties (e.g., texture, structure and soil organic matter) affect the size and amount of soil pores, and determine how easily water infiltrates and is held in the soil. Larger soil pores and fissures present in coarse textured soils generally allow faster infiltration while water infiltrates more slowly in fine textured soils.

Soil Structure

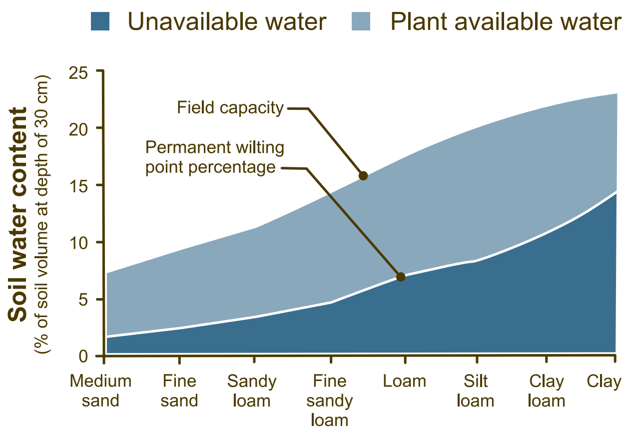
Well-structured soil with stable aggregates and an extensive network of pores allows water to infiltrate much easier than a poorly structured, compacted soil. Organic matter in a soil also influences infiltration in a couple of ways:

- Organic matter (especially coarse organic matter) is extremely porous so it allows water to infiltrate relatively easily.
- Organic matter enhances soil aggregate stability, which helps the soil to resist particle detachment by erosive forces and also promotes infiltration.

Soil Water Holding Capacity

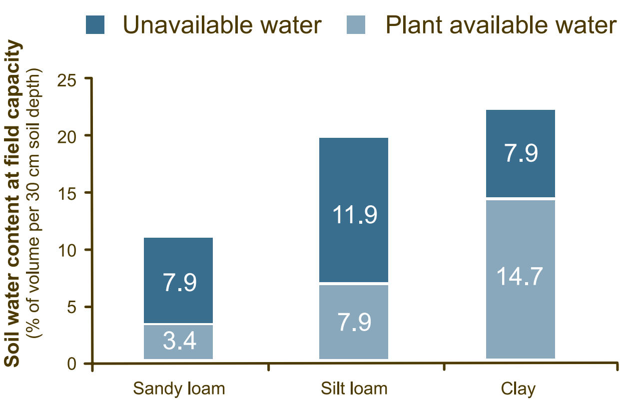
The soil's ability to handle water once it has infiltrated (i.e., water holding capacity) is determined by texture and organic matter content. Medium textured soils generally have the highest plant-available water content (Figures 8.1.2, 8.1.3). Organic matter content is positively related to water-holding capacity of the soil since organic materials act like a sponge and can absorb several times their dry weight in water. Increased water holding capacity reduces the potential for erosion that can occur as a result of poor soil structure or texture (e.g., eroded soils, low organic matter soils).

While soil texture cannot be controlled, management and cropping practices can have an important impact on soil properties. Practices that retain or build organic matter and improve soil structure will improve the infiltration and water-holding potential of the soil.



Drawn from data presented in Miller and Donoghue, 1990

Figure 8.1.2 Effect of Soil Texture on Soil Water Holding Capacity



Drawn from data presented in Miller and Donoghue, 1990

Figure 8.1.3 Water Holding Capacities of Three Soils at Field Capacity

Slope

Soil slope has an important effect on runoff since a higher level of erosive energy is generated by water moving over steep slopes than by water moving over shallow slopes. Although precipitation and soil properties cannot be managed, there are management practices designed to reduce water erosion potential by interrupting the uniformity of the slope or by breaking slopes up into shorter segments. These act to slow down the runoff reducing the energy that can be used for erosion and allowing the soil particles suspended in runoff to be deposited back onto the soil.

Length and the grade of a slope influence potential soil (and therefore nutrient) loss. Simulations using the Water Erosion Prediction Project (WEPP) software with Alberta data demonstrate that the volume of runoff (measured as depth of runoff) increases as a product of slope length and grade (Figure 8.1.4).

WEPP

The WEPP model was developed in the United States through a collaborative effort between the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS), the National (US) Soil Erosion Laboratory (NSERL) and Purdue University. It is designed to predict soil erosion losses at a field scale. The model incorporates soil, slope and climatic information to allow the user to see how management factors such as filter strips impact on soil losses.

To download and/or learn more about the WEPP model and its applications, you can visit the USDA-ARS website www.ars.usda.gov/main (search keyword: WEPP or NSERL).

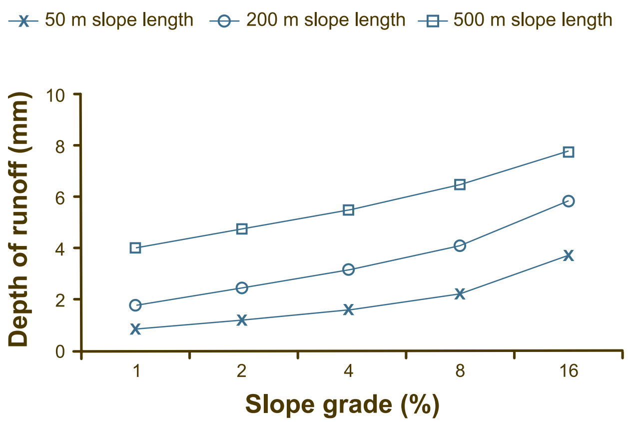
sidebar

The proportion of water available for plant use when a soil is moist but not saturated (i.e., at field capacity) will vary according to organic matter content, pore space and soil texture.

more info

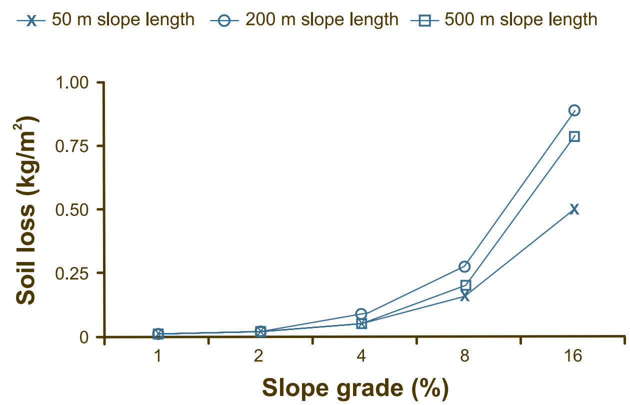
For information on the soil temperature issue in direct seeding systems, consult the following resource, available from the AF Publications Office (1-800-292-5697) or search by Agdex number on Ropin the Web.

- **Froebel, B. and Howard, A. 1999. Soil temperature and direct seeding. AF. Agdex 590-2.**



Provided by Andy Jedrych, AF

Figure 8.1.4 Predicted Runoff Volume (measured as runoff depth as a function of slope grade for slopes 50 m, 200 m and 500 m in length). From data generated for a WEPP simulation for a loam textured soil in central Alberta climatic conditions.



Provided by Andy Jedrych, AF

Figure 8.1.5 Predicted Surface Soil Loss, kg/m^2 as a Function of Slope Grade (for slopes 50 m, 200 m and 500 m in length). From data generated for a WEPP simulation for a loam textured soil in central Alberta climatic conditions.

The volume of runoff from a site increases with increased grade and increased length of slope. An increase in the grade of the slope increases the gravitational force on water and, depending on soil factors (i.e., permeability, texture, etc.), may increase its tendency to flow along the surface rather than infiltrate into the soil. The relationship between runoff and soil/nutrient loss is illustrated in Figure 8.1.5.

Generally, the longer and steeper the slope the greater the sediment loss will be (Figure 8.1.5). In addition, soil loss is a function of soil texture, land use (e.g., crop type and stage, tillage regime) and climatic conditions. The energy of the water to detach sediment particles from the soil surface increases as the volume and intensity of the runoff increases.

Vegetation or Ground Cover

Many erosion control measures provide ground cover to protect the soil. It is particularly useful if ground cover is maintained high-risk periods such as during snowmelt runoff. Ground cover limits runoff by providing a physical barrier, which also increases the chance for runoff to infiltrate. Vegetative cover also serves as a filter to increase the removal of particles from runoff. Ground cover can be present in the form of living plants or as residue from the previous crop (Figure 8.1.6).

Vegetation and ground cover have several important effects on rainfall and runoff water:

- **Raindrop Buffering Effect.** Plants or plant residues reduce the impact of raindrops on the soil by intercepting raindrops and absorbing much of the energy. When raindrops strike bare soils, they can fracture soil aggregates and cause smaller particles to wash into and effectively plug soil pores. This reduces the permeability of surface soil layers resulting in reduced water infiltration.
- **Soil Channelling Effect.** Small channels created by intact stems and roots can serve as tiny "pipelines" that facilitate water movement into the soil. This effect is enhanced when a living canopy of leaves is present as these serve to direct precipitation towards the stem in a process referred to as "stem flow".
- **Reservoir Effect.** Ground cover serves as a sort of in-field "reservoir" delaying the movement of water off the field and allowing more time for water to infiltrate. The stems of plants or standing crop residues serve as a physical barrier to water movement while vegetative debris on the surface may absorb some of the water and release it gradually so that it can be absorbed over a longer period of time.

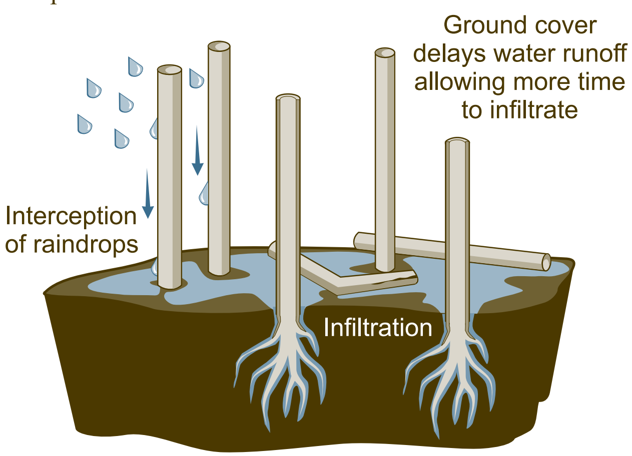


Figure 8.1.6 Ground Cover Enhances Water Infiltration and Control Runoff

Crop Residues and Soil Temperature

Crop residues reduce the severity of runoff in the spring by serving as a barrier against runoff as well as improving runoff infiltration into the soil. Crop residues left on the soil surface also trap snow, which serves as an insulation buffer against extremes in soil temperature. The cooler, moister conditions that result can delay seeding in direct seeding or reduced tillage management systems since the soil warms more slowly in the spring.

summary

- Runoff and water erosion can transport nutrients from the field either dissolved in solution or associated with soil particles reducing the amount of nutrients available to support crop production.
- Precipitation patterns are a major factor in the generation of runoff. Most of the runoff in Alberta is generated by snowmelt.
- Timing and rate of precipitation are critical factors affecting runoff. High intensity storms will cause more runoff than low intensity storms.
- The condition of the soil at the time of rainfall or runoff is also important. Wet soils generally have lower infiltration rates than dry soils since pore spaces are already filled with water.
- Soil properties including texture, structure and organic matter content have important influences on the permeability of a soil to water and its ability to hold water once it has infiltrated.
- Length and grade of slopes in a field impact soil erosion and therefore nutrient losses. Several runoff control practices are designed to interrupt the continuity of slopes to interfere with free-flow of runoff down slope.
- Ground cover in the form of vegetation or crop residue can reduce erosion and nutrient losses by providing a physical barrier and protecting the soil surface from the erosive energy of rainfall, snowmelt and concentrated flow.