Factsheet

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Soil Erosion — Causes and Effects

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Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water (Figure 1) and wind (Figure 2) or through forces associated with farming activities such as tillage.

Erosion, whether it is by water, wind or tillage, involves three distinct actions — soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes.

Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process.

This factsheet looks at the causes and effects of water, wind and tillage erosion on agricultural land.

Figure 1. The erosive force of water from concentrated surface water runoff.

Figure 2. The erosive force of wind on an open field.

WATER EROSION

The widespread occurrence of water erosion combined with the severity of on-site and off-site impacts have made water erosion the focus of soil conservation efforts in Ontario.

The rate and magnitude of soil erosion by water is controlled by the following factors:

Rainfall Intensity and Runoff Volumes

The greater the intensity and duration of a rainstorm, the higher the erosion potential. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials detached by rainfall splash, such as very fine sand, silt, clay and organic matter are easily transported by runoff water. Greater raindrop energy and runoff amounts are required to move and carry larger sand and gravel particles.

Soil detachment by rainfall (raindrop splash) is usually greatest and most noticeable when bare soils are exposed to short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not usually as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time or when these events occur at times when the soil has limited protective vegetative cover.

Surface water runoff occurs whenever there is excess water on a slope that cannot infiltrate the soil or pond on the surface. Reduced infiltration due to soil compaction, crusting or frozen soils increases the likelihood of runoff. Runoff from agricultural land is greatest during later winter, early spring months when the soils are typically saturated, snow is melting and vegetative cover and growth are minimal.

Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal characteristic affecting erodibility, but structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils.

Tillage and cropping practices that reduce soil organic matter levels, contribute to poor soil structure or result in soil compaction, lead to increases in soil erodibility. As an example, compacted subsurface soil layers can decrease infiltration and increase runoff. The formation of a soil crust, which tends to "seal" the surface, also decreases infiltration. On some sites, a soil crust might decrease the amount of soil loss from raindrop impact and splash; however, a corresponding increase in the amount of runoff water can contribute to more serious erosion problems.

Past erosion also affects a soil's erodibility. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils were because of their poorer structure and lower organic matter. The lower nutrient levels often associated with subsoils contribute to lower crop yields and generally poorer crop vegetative cover, which in turn provides less crop protection for the soil.

Slope Gradient and Length

The steeper and longer the slope of a field, the higher the risk for erosion. Soil erosion by water increases as the slope length increases due to the greater accumulation and energy associated with the runoff. Consolidation of small fields into larger ones often results in longer slope lengths, increasing erosion potential due to increased velocity of water, which permits a greater degree of scouring (carrying capacity for sediment). Crop management systems that incorporate contour farming and strip-cropping techniques interrupt long slopes and help reduce the amount of erosion.

Cropping and Vegetation

The potential for soil erosion increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash and tends to slow down the movement of runoff water, allowing more time for this surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or crop residues depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil and intercept all falling raindrops at and close to the surface are the most efficient in controlling soil erosion (e.g., forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

The effectiveness of any protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. Crops that provide a full protective cover for a major portion of the year (e.g., alfalfa or winter cover crops) can reduce erosion much more than can crops that leave the soil bare for a longer period of time (e.g., row crops), particularly during periods of highly erosive rainfall such as the spring and summer. To reduce erosion on annual row-crop land, leaving greater than 30% residue cover, or establishing a cover crop (e.g., red clover in wheat, oats after silage corn) over the winter months is recommended.

Tillage Practices

The potential for soil erosion by water is affected by tillage operations, depending on the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing water erosion. Minimum till or no-till practices are effective in reducing soil erosion by water.

Tillage and other practices performed up and down field slopes creates pathways for surface water runoff and can accelerate the soil erosion process.

Forms of Water Erosion

Sheet Erosion

Sheet erosion is the movement of soil from raindrop splash and runoff water. It typically occurs evenly over a uniform sloped area and goes unnoticed until most of the productive topsoil has been lost. Deposition of the eroded soil occurs at the bottom of the slope (Figure 3) or in low areas. Lighter-coloured soils on knolls, changes in soil horizon thickness and low crop yields on shoulder slopes and knolls are other indicators.

Rill Erosion

Rill erosion results when surface water runoff concentrates, forming small yet well-defined channels (Figure 4). These distinct channels where the soil has been washed away are called rills when they are small enough to not interfere with field machinery operations. In many cases, rills are filled in each year as part of tillage operations.

Figure 3. The accumulation of soil and crop debris at the lower end of this field is an indicator of sheet erosion.

Figure 4. The presence of distinct and sometimes parallel channels where the soil has been washed away by surface water runoff is an indicator of rill erosion.

Gully Erosion

Gully erosion is an advanced stage of rill erosion where surface channels are eroded to the point where they become a nuisance factor in normal tillage operations (Figure 5). There are farms in Ontario that are losing large quantities of topsoil and subsoil each year due to gully erosion. Surface water runoff, causing gully formation or the enlarging of existing gullies, is often the result of improper outlet design for local surface and subsurface drainage systems. The soil instability of gully banks, usually associated with seepage of groundwater, leads to sloughing and slumping (caving-in) of bank slopes. Such failures usually occur during spring months when the soil moisture conditions are at their highest.

Gully formations are difficult to control if corrective measures are not designed and properly constructed. Control measures must consider the cause of the increased flow of water across the landscape and be capable of directing the runoff to a proper outlet. Gully erosion results in significant amounts of land being taken out of production, contributes to a good portion of the sediment loads leaving cropland and creates hazardous conditions for the operators of farm machinery.

Bank Erosion

Natural streams and constructed drainage channels act as outlets for surface water runoff and subsurface drainage systems. Bank erosion is the progressive undercutting, scouring and slumping of these drainageways (Figure 6). Poor construction practices, inadequate maintenance, uncontrolled livestock access and cropping too close can all lead to bank erosion problems.

Poorly constructed tile outlets also contribute to bank erosion. Some do not function properly because they have no rigid outlet pipe, have an inadequate splash pad or no splash pad at all, or have outlet pipes that have been damaged by erosion, machinery or bank cave-ins.

The direct damages from bank erosion include loss of productive farmland, undermining of structures such as bridges, increased need to clean out and maintain drainage channels and washing out of lanes, roads and fence rows.

Figure 5. Gully erosion may develop in locations where rill erosion has not been managed.

Figure 6. Bank erosion involves the undercutting and scouring of natural stream and drainage channel banks.

Effects of Water Erosion

On-Site

The implications of soil erosion by water extend beyond the removal of valuable topsoil. Crop emergence, growth and yield are directly affected by the loss of natural nutrients and applied fertilizers. Seeds and plants can be disturbed or completely removed by the erosion. Organic matter from the soil, residues and any applied manure, is relatively lightweight and can be readily transported off the field, particularly during spring thaw conditions. Pesticides may also be carried off the site with the eroded soil.

Soil quality, structure, stability and texture can be affected by the loss of soil. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the soil's structural integrity. This in turn affects the water-holding capacity of the soil, making it more susceptible to extreme conditions such as drought.

Off-Site

The off-site impacts of soil erosion by water are not always as apparent as the on-site effects. Eroded soil, deposited down slope, inhibits or delays the emergence of seeds, buries small seedlings and necessitates replanting in the affected areas. Also, sediment can accumulate off-site on down-slope properties and contribute to road damage.

Sediment that reaches streams or watercourses can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat and degrade downstream water quality. Pesticides and fertilizers, frequently transported along with the eroding soil, contaminate or pollute downstream water sources, wetlands and lakes. Because of the potential seriousness of some of the off-site impacts, the control of "non-point" pollution from agricultural land is an important consideration.

WIND EROSION

Wind erosion occurs in susceptible areas of Ontario but represents a small percentage of land — mainly sandy and organic or muck soils. Under the right conditions, however, it can cause major movement and loss of valuable top soil (Figure 7).

Soil particles move in three ways, depending on soil particle size and wind strength — suspension, saltation and surface creep.

Figure 7. Wind erosion can be severe on open, unsheltered fields. Wind-blown particles will accumulate along field boundaries.

The rate and magnitude of soil erosion by wind is controlled by the following factors:

Soil Erodibility

Very fine soil particles are carried high into the air by the wind and transported great distances (suspension). Fine-to-medium size soil particles are lifted a short distance into the air and drop back to the soil surface, damaging crops and dislodging more soil (saltation). Larger-sized soil particles that are too large to be lifted off the ground are dislodged by the wind and roll along the soil surface (surface creep). The abrasion that results from windblown particles breaks down stable surface aggregates and further increases the soil erodibility.

Soil Surface Roughness

Soil surfaces that are not rough offer little resistance to the wind. However, ridges left from tillage can dry out more quickly in a wind event, resulting in more loose, dry soil available to blow. Over time, soil surfaces become filled in, and the roughness is broken down by abrasion. This results in a smoother surface susceptible to the wind. Excess tillage can contribute to soil structure breakdown and increase wind erosion susceptibility.

Climate

The speed and duration of the wind have a direct relationship to the extent of soil erosion by wind. Soil moisture levels are very low at the surface of excessively drained soils or during periods of drought, thus releasing the particles for transport by wind. This effect also occurs with freeze-drying of the soil surface during winter months. Accumulation of soil on the leeward side of barriers such as fence rows, trees or buildings, or snow cover that has a brown colour during winter, are indicators that wind erosion is occurring.

Unsheltered Distance

A lack of windbreaks (trees, shrubs, crop residue, etc.) allows the wind to put soil particles into motion for greater distances, thus increasing abrasion and soil erosion. Knolls and hilltops are usually exposed and suffer the most.

Vegetative Cover

The lack of permanent vegetative cover in certain locations results in extensive wind erosion. Loose, dry, bare soil is the most susceptible; however, crops that produce low levels of residue (e.g., soybeans and many vegetable crops) may not provide enough resistance. In severe cases, even crops that produce a lot of residue may not protect the soil.

The most effective protective vegetative cover consists of a cover crop with an adequate network of living windbreaks in combination with good tillage, residue management and crop selection.

Effects of Wind Erosion

Wind erosion damages crops through the sandblasting of young seedlings or transplants, burial of plants or seed, and exposure of seed. Crops are ruined, resulting in costly delays and making reseeding necessary. Plants damaged by sandblasting are vulnerable to the entry of disease with a resulting decrease in yield, loss of quality and market value. Also, wind erosion can create adverse operating conditions, preventing timely field activities.

Soil drifting is a fertility-depleting process that can lead to poor crop growth and yield reductions in areas of fields where wind erosion is a recurring problem. Continual drifting of an area gradually causes a textural change in the soil. Loss of fine sand, silt, clay and organic particles from sandy soils serves to lower the moisture-holding capacity of the soil. This increases the erodibility of the soil and compounds the problem.

The removal of wind-blown soils from fence rows, constructed drainage channels and roads, and from around buildings is a costly process. Also, soil nutrients and surface-applied chemicals can be carried along with the soil particles, contributing to off-site impacts. In addition, blowing dust can affect human health and create public safety hazards.

Figure 8. Tillage erosion involves the progressive down-slope movement of soil.

TILLAGE EROSION

Tillage erosion is the redistribution of soil through the action of tillage and gravity (Figure 8). It results in the progressive down-slope movement of soil, causing severe soil loss on upper-slope positions and accumulation in lower-slope positions. This form of erosion is a major delivery mechanism for water erosion. Tillage action moves soil to convergent areas of a field where surface water runoff concentrates. Also, exposed subsoil is highly erodible to the forces of water and wind. Tillage erosion has the greatest potential for the "on-site" movement of soil and in many cases can cause more net movement of soils across a field than water or wind.

The rate and magnitude of soil erosion by tillage is controlled by the following factors:

Type of Tillage Equipment

Tillage equipment that lifts and carries will tend to move more soil. As an example, a chisel plow leaves far more crop residue on the soil surface than the conventional moldboard plow but it can move as much soil as the moldboard plow and move it to a greater distance. Using implements that do not move very much soil will help minimize the effects of tillage erosion.

Direction

Tillage implements like a plow or disc throw soil either up or down slope, depending on the direction of tillage. Typically, more soil is moved while tilling in the down-slope direction than while tilling in the up-slope direction.

Speed and Depth

The speed and depth of tillage operations will influence the amount of soil moved. Deep tillage disturbs more soil, while increased speed moves soil farther.

Number of Passes

Reducing the number of passes of tillage equipment reduces the movement of soil. It also leaves more crop residue on the soil surface and reduces pulverization of the soil aggregates, both of which can help resist water and wind erosion.

Effects of Tillage Erosion

Tillage erosion impacts crop development and yield. Crop growth on field areas impacted by tillage erosion such as shoulder slopes and knolls is slow and stunted due to poor soil structure and loss of organic matter and is more susceptible to stress under adverse conditions. Changes in soil structure and texture can increase the erodibility of the soil and expose the soil to further erosion by the forces of water and wind.

In extreme cases, tillage erosion includes the movement of subsurface soil. Subsoil that has been moved from upper-slope positions to lower-slope positions can bury the productive topsoil in the lower-slope areas, further impacting crop development and yield. Research related to tillage-eroded fields has shown soil loss of as much as 2 m of depth on upper-slope positions and yield declines of up to 40% in corn. Remediation for extreme cases involves the relocation of displaced soils back to the upper-slope positions.

CONSERVATION MEASURES

The adoption of various soil conservation measures reduces soil erosion by water, wind and tillage. Tillage and cropping practices, as well as land management practices, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches or more extreme measures might be necessary. For example, contour plowing, strip-cropping or terracing may be considered. In more serious cases where concentrated runoff occurs, it is necessary to include structural controls as part of the overall solution — grassed waterways, drop pipe and grade control structures, rock chutes, and water and sediment control basins.

More details on these and other best management practices can be found in the Best Management Practices publication — *Controlling Soil Erosion on the Farm*.

SUMMARY

Soil erosion remains a key challenge for Ontario agriculture. Many farmers have already made significant progress in dealing with soil erosion problems on their farms. However, because of continued advances in soil management and crop production technology that have maintained or increased yields in spite of soil erosion, others are not aware of this yield-limiting problem on farmland. Awareness usually occurs only when property is damaged and productive areas of soil are lost.

The increase in extreme weather events and warmer winters predicted with climate change will further increase water and wind erosion potential and create new areas of concern for Ontario. Farmland must be protected as much as possible, with special attention given to higher erosion risk situations where our soils are most vulnerable.

RESOURCES

OMAFRA factsheet, *Universal Soil Loss Equation*

Best Management Practices, *Soil Management*

Best Management Practices publications

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