Voluntary Clean Water Guidance for Agriculture Chapters

The purpose of this guidance is to describe best management practices (BMPs) that agricultural producers can use to protect water quality. It is intended to both support healthy farms while helping producers meet clean water standards. The Voluntary Clean Water Guidance introduction[1] provides overall goals and objectives, as well as information on how the guidance will be used. Readers are encouraged to read the overall introduction before this chapter.

Chapter 1 Cropping Methods: Tillage & Residue Management

Chapter 2 Cropping Methods: Crop System

Chapter 3 Nutrient Management

Chapter 4 Pesticide Management

Chapter 5 Sediment Control: Soil Stabilization & Sediment Capture (Vegetative)

Chapter 6 Sediment Control: Soil Stabilization & Sediment Capture (Structural)

Chapter 7 Water Management: Irrigation Systems & Management

Chapter 8 Water Management: Subsurface Drainage Management

Chapter 9 Runoff Control for Agricultural Facilities

Chapter 10 Livestock Management-Pasture & Rangeland Grazing

Chapter 11 Livestock Management-Animal Confinement, Manure Handling & Storage

Chapter 12 Riparian Areas & Surface Water Protection

Chapter 13 Suites of Recommended Practices

This report is available on the Department of Ecology's website at https://apps.ecology.wa.gov/publications/SummaryPages/2010008.html[2]

[1] https://apps.ecology.wa.gov/publications/documents/2010008.pdf

[2] https://apps.ecology.wa.gov/publications/SummaryPages/2210002.html

Chapter 5—Draft

Sediment Control: Soil Stabilization & Sediment Capture (Vegetative)

Voluntary Clean Water Guidance for Agriculture

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July 2025
Publication Number 20-10-008g

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Table of Contents

List of Figures and Tables

Figures

Tables

Recommendations for Sediment Control: Soil Stabilization & Sediment Capture (Vegetative) to Protect Water Quality

The Voluntary Clean Water Guidance introduction[3] provides overall goals and objectives, as well as information on how the guidance will be used. Readers are encouraged to read the overall introduction before this chapter.

Introduction

This chapter focuses on the use of vegetation to stabilize and capture sediment on cropland, orchards, pastures, and rangelands. The majority of recommended Best Management Practices (BMPs) are designed to lessen or prevent the mobilization and transport of sediment during periods of runoff. The one exception are windbreaks, which are designed to reduce the impact of wind erosion during the dry season.

Practice designed to stabilize sediment on the field include conservation cover, contour filter strips, and cover crops, are designed to stabilize sediment on the field. Edge-of-field practices (with some in-field applications) that intercept and capture sediment as it leaves the field include grassed waterways, filter strips, and vegetated treatment areas (VTAs).

These practices are not meant to be used in isolation, instead they can be used in combination to decrease the chances of sediment transport during storm events. Most erosion occurs during these storm events, which can vary in size and intensity. The varied nature of storm events is likely closely related to how well these BMPs can prevent and capture erosion along with additional variables such soil type, topography, type of agriculture and associated farming activities.

Scope of Guidance

The purpose of this chapter is to outline BMPs, that when implemented, will help prevent negative impacts to water quality from sediment (reductions in nutrients and bacteria are a likely benefit as well). As such, this chapter provides recommendations on how to stabilize soil in-field and capture sediment at the edge-of-field before entering surface water.

The practices outlined in this chapter are primarily source control BMPs that are intended to prevent pollutants from coming into contact with water and/or are designed to capture polluted runoff. Further, these practices should be implemented in suites as their efficacy often requires that all components are functioning properly. Ultimately, the goal is to prevent

[3] https://apps.ecology.wa.gov/publications/documents/2010008.pdf

pollution from leaving the site. While the primary focus of these recommendations are to protect water quality, many of these practices also provide operational benefits as well.

Definitions as Used in this Document

General Definitions

Ephemeral (surface water): Flow typically with a short-lived presence.

Groundwater: As opposed to surface water, groundwater is water that has infiltrated from the land surface and is retained in the soil or in pores and crevices in rock.

Intermittent (surface water): Flow that occurs at irregular intervals as opposed to perennial flow which has a continuous presence.

Perennial (surface water): Flow that occurs continuously, though of varying levels.

Swale: A shallow depression in the ground that collects and transports water.

Sheet Erosion: A shallow uniform layer of water that picks up and transports sediment over a wide area.

Rill Erosion: Erosion by concentrated flow in small, sometimes parallel, channels.

Gully Erosion: Similar to rill erosion with larger channels.

Riparian Buffer: A vegetative strip, of varying width, adjacent to a surface water, that provides for water quality benefits through shading and runoff pollutant removal.

Concentrated Flow: Any surface runoff that is not shallow overland or sheet flow.

Prevailing Wind: a surface wind that blows predominantly from a particular direction.

Definitions of Sediment Control Practices

Conservation Cover: Permanent herbaceous vegetative cover planted in areas that would otherwise be exposed earth (e.g. between rows of grapevines, fruit trees, etc.) to prevent erosion (NRCS, 2024).

Contour Filter Strip: Strips of permanent vegetative cover established on the contours of a hillslope which alternates downslope with wider cropped strips, also farmed along the contour (NRCS, 2016).

Cover Crop: Herbaceous vegetative cover planted as seasonal cover in rotation with annual production crops (NRCS, 2024).

Filter Strip: Also known as a Vegetative Filter Strip (VFS) are typically comprised of grass and designed to receive runoff for the purpose of pollutant removal (NRCS, 2017).

Grassed Waterway: A broad and shallow shaped, or naturally occurring, channel established with herbaceous (usually grasses) vegetation to convey surface water, at a reduced velocity, to a stable outlet with minimal sediment transport (NRCS, 2025).

Vegetated Treatment Area: An area of permanent herbaceous, woody, or mixed vegetation established to allow for infiltration and processing of agricultural runoff (NRCS, 2023).

Windbreak: also known as a shelterbelt, consists of single/multiple rows of trees and/or shrubs planted in a linear, or curvilinear, fashion perpendicular to prevailing winds (NRCS, 2022).

Recommendations

The following practices are recommended to prevent sediment from leaving agricultural areas and entering surface waters using vegetation (preferably native where appropriate). These BMPs are divided into primary (soil stabilization) and secondary (sediment capture) practices. Other methods of erosion control related to tillage, runoff, and livestock are found in other chapters (Chapters 1, 6 & 9, and 10 respectively).

Function/Purpose

The primary recommended practices are designed to keep soil on field and reduce the potential for sediment, and associated contaminants, from entering surface waters. The overall goals of these practices are to reduce the aerial extent and amount of time agricultural fields have bare soils. This has the added benefit of retaining soil and beneficial nutrients in-field. Secondary practices, either in-field or directly connected to agricultural activities, reduce runoff velocities, promote infiltration, and capture sediment in areas that are likely to have concentrated flows, thus allowing runoff from the field to be disconnected from surface waters. The capture and interception (secondary) BMPs generally most effective when used in combination with one or more soil stabilization BMPs listed above. Both primary and secondary practices are more effective when used in combination with the recommended tillage and residue management (Chapter 1) and/or pasture and rangeland (Chapter 10) practices outlined in of the Voluntary Clean Water Guidance for Agriculture **(**VCWG).

BMP Recommendations for Sediment Stabilization

The following practices are designed to retain soil in-field and prevent mechanical erosion from wind and water.

- Windbreaks
- Conservation Cover
- Contour Filter Strips
- Cover Crops

Windbreaks

Windbreaks are designed to slow windspeeds at the surface level to reduce the potential for soil to be picked up and transported off field. Wind erosion process can affect soil health and potentially contaminate nearby surface waters.

Airborne sediment particles can be deposited on nearby water sources. This can increase turbidity and be a transport mechanism for nutrients and contaminants that are attached to the sediment particles. Indirect impacts to water quality can also occur through an increase in the intensity of water erosion and drainage passageways during rain events.

A row, or multiple rows, of tall dense trees can affect surface winds for a wide swath of the landscape, both before and after the windbreak. Conifers, especially Cedar trees, provide a solid wall of vegetation horizontally and vertically throughout the year but may not be applicable everywhere, as discussed below. Tall broadleaf trees, such as Poplars, can also be effective if the leaves extend throughout the structure of the windbreak, however they are less effective during the leaf off period.

The rows of trees are most effective when oriented perpendicular to the prevailing winds. The United States Department of Agriculture (USDA) provides data on wind direction throughout the country with the Wind Rose dataset[4].

There are some areas of Washington State (parts of the Columbia Plateau) that do not naturally support large trees. An alternative practice of planting hedge rows perpendicular to the prevailing winds can also help prevent wind erosion. Hedge rows will not be as tall as a traditional windbreak, and they will protect less of the surrounding area. Typically, multiple hedgerows are planted throughout the field, with crops in-between. One study found that 24 meter (79 feet) spacing between hedge rows reduced windspeed by 50% (Böhm et al., 2014). It is likely that spacing hedge rows between 50-100 feet would be effective in most areas, however windspeeds and wind directions vary significantly throughout the state and a single recommendation cannot be made. Wind models and equations are presented in Appendix A and can be used to estimate desired hedge row spacing throughout the state.

Windbreaks (hedged or treed) can also be placed strategically to provide additional protections in sensitive areas. Placing windbreaks around streams (perennial, ephemeral, or intermittent) will provide riparian buffer protection as well (see Chapter 12 for recommendations). Windbreaks can also be established at the edge of field to block sediment from leaving the area. This can also stabilize any roadside ditch that may parallel the field, filter strips (see below

[4] https://www.nrcs.usda.gov/programs-initiatives/sswsf-snow-survey-and-water-supply-forecasting-program/wind-rose-data

for recommendations) at the base of the windbreak will also help prevent sediment from entering roadside ditches associated with runoff.

Agroforestry is also an option to provide revenue from land converted to windbreaks. Fruit and nut trees can be harvested annually, or trees can be planted and harvested for wood products, such as lumber. If planting wood products it is important that windbreaks are multi-aged and contain multiple rows so that trees can be harvested at different times and the overall structure of the windbreak remains intact.

Recommendations and Considerations

- The preferred option is for a multi-height row (or multiple rows) of conifer trees (Western WA and parts of Eastern WA that support conifer species).
- All windbreak options should be oriented perpendicular to the prevailing winds.
- Broadleaf trees, such as Poplars, are a secondary option in areas that do not support coniferous trees (e.g. areas with partially hydric soils).
- Primary locations should be along streams to provide riparian buffers as well (see Chapter 12 for recommendations).
- Secondary locations should be at the edge of the field to provide additional protection of NRCS practice 386: field border (NRCS, 2016).
- Hedge rows may be another option in areas that do not support large trees (parts of the Columbia Plateau).
    - Multiple hedge rows may be needed throughout the field to provide the same protection as a treed windbreak.
    - Hedge rows within field could be used in combination with contour filter strips (see below) to also prevent water erosion and temperature increases.
- Agroforestry can be used to provide supplemental income.
- To be used in conjunction with tillage practices recommended in Chapter 1.

Conservation Cover

Perennial woody crops and cane (e.g. fruit trees, grapevines, and berry plants) are planted in well-established rows that can persist for years or decades. The area between these rows can be highly to sheet, rill, and gully erosion. This can be exacerbated by agricultural machinery that can compact the ground or create ruts which provides pathways for concentrated flows during rain events.

Perennial cover crops, such as grasses, stabilize the soil between rows with the root structure and can capture sediment with the vegetated part of the plant. It is important to use perennial species that go dormant during the dry season to maximize the erosion control benefits and limit the competition for resources with the main crop. Mowing the cover crop at the beginning of the dry season will induce dormancy and limit competition for water. By the start of the wet season, vegetated parts will reemerge to provide sediment capture. Leaving the residue (i.e. mulching) of the cover crop can also provide additional nutrients to the main crop during the vegetative growth period of the cycle.

Areas directly under vines and berry bushes may still be susceptible to erosion when this area is kept clear to limit competition for water with the main crop. Creeping varieties of plants can provide cover and protection from erosion by growing over the roots of the main crop without impacting the root structure. There is also evidence that this practice can help retain soil moisture.

Recommendations and Considerations

- Dwarf grasses (e.g. *Festuca ovina*) are recommended for inter-row planting in orchards, vineyards, and berry farms.
- Mowing or mulching of the grasses should occur, at minimum, at the beginning of the dry season.
- Additional mowings to minimize competition can be performed to coincide with different phenological stages of the crop (See Figure 6 in Appendix A).
- Creeping plants are recommended for areas directly beneath grape vines and berry plants.

Contour Filter Strips

Adding filter strips to a contour farming operation can reduce runoff, trap sediment and promote infiltration of water (See Chapter 2 for contour farming BMPs). These strips alternate with row crops horizontally along the contour of the landscape. Filter strips can be established on terraces or planted along the natural grade of the slope. The same concepts apply to both, with terrace farming occurring on steeper slopes while contour farming is only effective n gentler slopes.

The most crucial location of a filter strip is at the lower end of the slope. This can be an edge of field practice or can be the outer zone of a riparian buffer (see Chapter 12). It is important that any additional runoff that continues through the upslope filter strips is not conveyed to surface waters. By adding filter strips upslope, runoff is reduced, water can infiltrate more slowly, and soil is more likely to remain in-field and not be transported to surface waters. This can have the added benefit of increasing soil moisture and health throughout the crop production area.

Filter strips are covered extensively in Chapter 12 of the VCWG as an alternative practice in the inner or outer zones of a riparian buffer. The same widths and site-specific recommendations in that chapter should apply to contour filter strips as well. The main difference is the location of this practice. The effectiveness of filter strips to reduce runoff and trap sediment is related to the structure of this practice. If the recommendations are followed, this BMP should be effective both in-field and as part of a riparian buffer.

Recommendations and Considerations

- In areas where terracing is used to cultivate steep lands. it is recommended to plant vegetation (e.g., filters strips or conservation cover) on the terrace slopes between terraced crops.
- When contour farming on gentler slopes, alternating filter strips with row crops is recommended.
- The final row, at the bottom of the slope, should be a filter strip.
- Width of the filter strips should follow the recommendations in Chapter 12 of the VCWG.
    - In western Washington, the width for filter strips is 15ft on Hydrologic Group A or B soils and 25ft on Hydrologic Group C or D soils.
    - In eastern Washington, the width for filter strips is 10ft on Hydrologic Group A or B soils and 20ft on Hydrologic Group C or D soils.
- Additional guidance on filter strips from Chapter 12, that relates to site specific factors, should also be applied.
- Priority should be given to native plants whenever possible.
- Permanent herbaceous vegetation (e.g., perennial grasses) that can withstand sedimentation, provides a high stem density, and is suited to the site conditions and purpose. .
- Use in conjunction with tillage and residue management practices as outlined in Chapter 1.

Cover Crops

After annual crops have been harvested, exposed soil is susceptible to sheet, rill, and gully erosion. Planting cover crops after the harvest helps prevent soil loss and sediment transport to surface waters during storm events. Tillage and residue management practices should also be paired with this practice (See Chapter 1 for recommendations).

Some crops (e.g. soybean and corn) are harvested closer to the onset of the fall rainy season. This may not provide enough time for cover crops to become fully established before large storm events occur. One method to plant earlier is to inter-seed the cover crops into the rows of corn or soybean prior to harvest. This allows the cover crops to develop root structures and become at least partially established before the crop is harvested. This is more likely to benefit lands west of the Cascade Mountains where the dominant period of precipitation and runoff is in the fall.

East of the Cascades inter-seeding may not be necessary, however selecting cold tolerant species, like cereal rye, can help with survival of the cover crop during the winter months. These crops can also be beneficial when late planting is needed due to harvest timings.

For recommendations on how cover crops fit into cropping strategies, see Chapter 2.

Recommendations and Considerations

- Seasonal cover crops are recommended to be planted after annual crop harvest.
- Inter-seeding in the late summer or early fall is recommended in areas where fall storm events are the primary source of precipitation and runoff (i.e. west of the Cascades).
- Cereal rye or winter wheat can be an effective crop for inter-seeding, however other grasses may also be a good alternative, if preferred.
- Cereal rye and other cold tolerant species are recommended for snow dominated areas (i.e. east of the Cascades).
- To be used in conjunction with tillage practices recommended in Chapter 1.

BMP Recommendations for Sediment Capture

The following practices are designed to capture sediment leaving an agricultural area to prevent contamination of surface waters.

- Grassed Waterways
- Filter Strips
- Vegetated Treatment Area

Grassed Waterways

Swales and other depressional areas can be a conveyance for large quantities of water moving at high velocity during storm events. By leaving these areas uncropped and planting grasses, water velocity is slowed and soils are stabilized, allowing for more infiltration, less erosion, and less transport of sediment. Roots stabilize the swale, and the vegetated part of the plant provides roughness to capture some of the sediment from connected agricultural lands. The effectiveness of sediment capture is highly variable and should not be relied upon as a primary sediment control practice. Instead, the main purpose of grassed waterways is to prevent gully erosion. Man-made grassed waterways should follow the recommended design to mimic a shallow channeled swale outlined in Chapter 9.

Using grassed waterways to control runoff from agricultural facilities is described in detail in Chapter 9. The recommendations to prevent gully erosion in Chapter 9 should apply here as well. The difference is that Chapter 9 mainly focuses on diversion of clean water to avoid contact from contaminated areas. Water coming off agricultural fields may be contaminated with nutrients or pathogens as well as sediment. Therefore, it is important that grassed waterways not only have a stable outlet, but that outlet should also be connected to another BMP (e.g. filter strip or vegetated treatment area) to allow for infiltration of any contaminated water before reaching surface water. Regular maintenance (see Appendix B, implementation considerations) is also important, which can be minimized by planting native grasses adapted to the local climate.

Recommendations and Considerations

- Grassed Waterways are recommended for depressional areas in-field that can convey runoff and create gullies.
- Man made grassed waterways shall consist of a wide bottom with shallow sloped walls.
- If gully erosion has already occurred, land can be graded and smoothed into a wide-bottomed grassed waterway.
- Stable outlets are required. This can be a large filter strip or a vegetated treatment area (see below) or another BMP that does not discharge to surface water (e.g. sediment control basin; see Chapter 6 for recommendations).
- Use NRCS specifications for Grass Waterways (NRCS code 412) when designing and installing a grassed waterway.

Filter Strips

The effectiveness and resulting guidance for filter strips is covered extensively in Chapter 12. As mentioned above, in the Contour Filter Strips section, filter strips are an alternative practice for the outer and inner zones of the recommended riparian buffers. Some of the Riparian Management Zone (RMZ) options allow for agroforestry/silvopasture or agricultural practices with all applicable BMPs. Including filter strips in these zones helps maximize infiltration of surface runoff and capture, retain, and/or transform the majority of pollutants before entering the core zone. This guidance should also apply to any areas where concentrated flow is likely, to help prevent runoff from reaching surface water.

Filter strips are also effective outside of RMZs to help prevent erosion and increase water infiltration. Areas that have a high potential for concentrated flow during storm events also have a high potential for erosion and potential sediment delivery to surface waters. Placing filter strips in these areas can keep soil in-field and prevent rill and gully erosion from creating pathways to surface water.

When pathways to surface water are already established, like areas adjacent to ditches and other artificial waterways, it is important to provide additional protections. Adding filter strips along ditches and artificial waterways can help stabilize the banks and prevent or minimize sediment from entering the ditch. Ditches and artificial waterways can be conduits to streams and other waterways, so it is important that water entering does not convey excess sediment to natural waterways. This can be accomplished by preventing sediment from entering the ditch or by disconnecting the artificial waterway from waters of the state. Vegetative treatment areas (see below for recommendations) and sediment control basins (see Chapter 6 for recommendations) can be a suitable location for the outlet of an artificial waterway. However, there are also some artificial waterways that may have once been streams or function like perennial or intermittent streams where full riparian protections, as outlined in Chapter 12, may be necessary to prevent reductions in water quality.

Most effectiveness research notes that the greatest benefit of filter strips is in the ability to maximize infiltration of runoff water into the soils. The additional benefit of roughness to capture sediment is only partially responsible for preventing erosion. This means that wider filter strips may be needed in areas where pathways to surface water exist to ensure that enough area is available for the runoff to infiltrate into the soil before reaching the artificial waterways. Steeper slopes can increase the velocity of the runoff during storm events and therefore might also need wider filter strips. Steeper sloped fields may also benefit from in-field contour filter strips (See Contour Filter Strips section for recommendations). Other site conditions may need wider strips or might allow for narrow filter strips depending on the topography of the landscape. It is also important that the flow is dispersed throughout as much of the filter strips as possible to prevent direct pathways through the filter strip. For additional information on the effectiveness of filter strips, see Chapter 12.

There are also some artificial waterways that may have once been streams or functioning like perennial or intermittent streams where Ecology may recommend the riparian protections outlined in Chapter 12.

Recommendations and Considerations

- Filter strips are recommended as a part of the RMZ configurations that allow for some agricultural uses in the inner and outer zones (see Chapter 12 for configurations and effectiveness of the practice).
- Filter strips not within a riparian management zone shall follow the minimum width guidelines laid out in Chapter 12 and recommended in the Contour Filter Strip section.
    - In western Washington, the width for filter strips is 15ft on Hydrologic Group A or B soils and 25ft on Hydrologic Group C or D soils.
    - In eastern Washington, the width for filter strips is 10ft on Hydrologic Group A or B soils and 20ft on Hydrologic Group C or D soils.
- Additional protections are needed for areas adjacent to artificial ditches and other artificial waterways (e.g. in-field, roadside ditches, etc.) to protect conveyances to surface water.
    - Increase width 10ft from the minimum (determined by the Hydrologic soil group).
    - Where soil slopes >8% occur within 215ft of the ditch, increase the filter strip width by an additional 10ft (See Contour Filter Strips section for additional steep slope recommendations).

    - A level spreader is a recommended BMP for placement at the upslope edge of the filter strip wherever concentrated flows (any surface runoff depth >1.2 inches) are known or suspected to occur.
- Larger widths than the minimums should be implemented where: topographic convergence occurs (e.g. swales, low spots, etc.); where surface flow is more likely to concentrate; rills or minor gullies tend to form; the hillslope is convex within 150ft of the ditch; and/or high intensity land uses occur adjacent to the filter strip. See examples of high intensity land uses presented earlier in Chapter 12.
    - Using the minimum filter strip widths may be implemented where topographic divergence occurs (e.g., a toe-slope of ridge where the slope fans out) within 150ft of the ditch; lower intensity agricultural uses are present; and/or other BMPs are being implemented upgradient or downgradient from the filter strip (e.g. disconnecting artificial waterways from surface water).
- Full riparian protections may be necessary for artificial waterways that are directly connected to perennial, artificial or perennial streams if there are no, or insufficient, upland BMPs present and/or the artificial waterway is flowing for more than 80% of a typical water year.
    - Alternatively, artificial waterways can be disconnected from surface water by having on outlet to a vegetated treatment area (see below) or sediment control basin (see Chapter 6).

Vegetated Treatment Area

Areas where large amounts of runoff from agricultural practices converge can be a conveyance for sediment, nutrients, and pathogens to surface water. Small amounts of runoff can be captured by filter strips and other BMPs. However, if runoff or agricultural drainage water exceeds the capacity of a filter strip, larger areas to allow for infiltration are needed. See Chapter 9 for recommendations related to this practice.

Recommendations and Considerations

- Install vegetated treatment areas where the volume of water cannot be infiltrated through a filter strip.
- Follow recommendations in Chapter 9.

NRCS Practices

- Windbreak-Shelterbelt Establishment and Renovation (NRCS practice code 380)
- Conservation Cover (NRCS practice code 313)
- Contour Buffer Strip (NRCS practice code 332)
- Cover Crop (NRCS practice code 340)
- Grassed Waterway (NRCS practice code 412)
- Filter Strip (NRCS practice code 393)

- Vegetated Treatment Area (NRCS practice code 615)

Commonly Associated Practices

- Tillage and Residue Management (Chapter 1)
- Crop Systems (Chapter 2)
- Nutrient Management (Chapter 3)
- Sediment Control Basins (Chapter 6)
- Runoff Management (Chapter 9)
- Riparian Buffers (Chapter 12)

Chapter 5 Appendix Part A: Effectiveness Synthesis (Sediment Control: Soil Stabilization & Sediment Capture (Vegetative))

Effectiveness

Soil loss through erosion is a global issue that is both a natural phenomenon and caused or accelerated by human activities (Ahmed et al., 2020; Zachar, 1982). Erosion on agricultural lands increases the loss of nutrients and soil moisture, pollutes surface water, and reduces agricultural and environmental productivity (Durán Zuazo & Rodríguez Pleguezuelo, 2008). Vegetative cover stabilizes soils through root structure and provides surface roughness aboveground that can capture sediment particles and increase water infiltration (De Baets et al., 2006; Durán Zuazo & Rodríguez Pleguezuelo, 2008; Fan & Su, 2008; Skidmore, 1986).

Field Retention of Sediment

The practices described below are designed to keep soil on fields and reduce the potential for sediment, and associated contaminants, from entering surface waters. This has the added benefit of retaining soil and beneficial nutrients in-field. These practices are most effective when used in combination with the tillage practices recommended in Chapter 1 (Cropping Methods: Tillage & Residue Management) of the VCWG.

Windbreaks

Over a third of the earth’s surface is naturally susceptible to wind erosion (Jarrah et al., 2020). This is more likely to occur in arid and semi-arid regions with periods of high wind velocities (Jarrah et al., 2020; Skidmore, 1986). During the dry season, when bare ground is exposed due to sparse or lack of vegetation, high winds pick up particles of the most fertile portion of the soil profile (Skidmore, 1986). This process accelerates with anthropogenic pressures such as over-harvesting vegetation, monoculture systems, deforestation, overgrazing rangelands, abandoning farmland, or leaving cultivated lands fallow for long periods of time (Jarrah et al., 2020).

Wind erosion can directly, and indirectly, deteriorate water quality (Feng & Sharratt, 2007; Sharratt et al., 2007; Skidmore, 2000; Tuo et al., 2016). Airborne sediments are deposited directly on water bodies, as well as in drainage pathways that can transport sediments during rain events (Skidmore, 2000). Wind erosion can also increase the intensity of water erosion, especially in areas of co-occurrence (Tuo et al., 2016). There are additional hazards associated with herbicides that may attach to airborne sediment particles that can contaminate off-site water quality (Larney et al., 1999). It is important for both air and water quality to minimize wind erosion associated with agricultural activities.

The use of windbreaks (also known as shelterbelts) extends as far back as the mid-1400s when the Scottish Parliament suggested planting trees to protect agricultural production (Brandle et al., 2004). Since then, windbreaks have been planted extensively across the globe to provide protection from wind erosion (Brandle et al., 2004). In the United States, the consequences of the 1930s dust bowl caused congress to pass the Prairie State Forestry Project to plant windbreaks in the affected areas (Brandle et al., 2004). Even with this long history of using shelterbelts to reduce wind erosion, the increase in mechanized and large-scale farming is a major cause for the persistence of this problem (Vacek et al., 2018).

Areas of the inland Pacific Northwest, especially the Columbia plateau, have persistent issues with soil and nutrient loss due to wind erosion (Pi et al., 2020). Sharratt et al. (2007) measured soil loss of 43 kg ha^{-1} in September 2003 and 2320 kg ha^{-1} in October 2003 from high-wind events. There is an estimated 5.5 Mg ha^{-1} of soil lost each year in the cultivated croplands (Pi et al., 2020; USDA, 2020). However, not all of this erosion is due to wind, runoff due to rain and snow melt is also an issue that is discussed below. Models, using data from 2003-2006, have estimated a mean daily soil loss is 0.4 Mg ha^{-1} during high wind events (Feng & Sharratt, 2007, 2009; Pi et al., 2020).

Soil is lost through surface winds (50-100 meters above land surface) which can also affect crop growth and development, animal health and the conditions on a farm or ranch (Brandle et al., 2004). Windbreaks interrupt these surface winds by creating roughness on the surface and frictional drag on the wind flow (Brandle et al., 2004; Skidmore, 1986). The winds are affected on the windward and leeward (Figure 1) side of the windbreak, 2 to 5 times the height of the barrier on the windward side and 10 to 30 times the height leeward (Brandle et al., 2004).

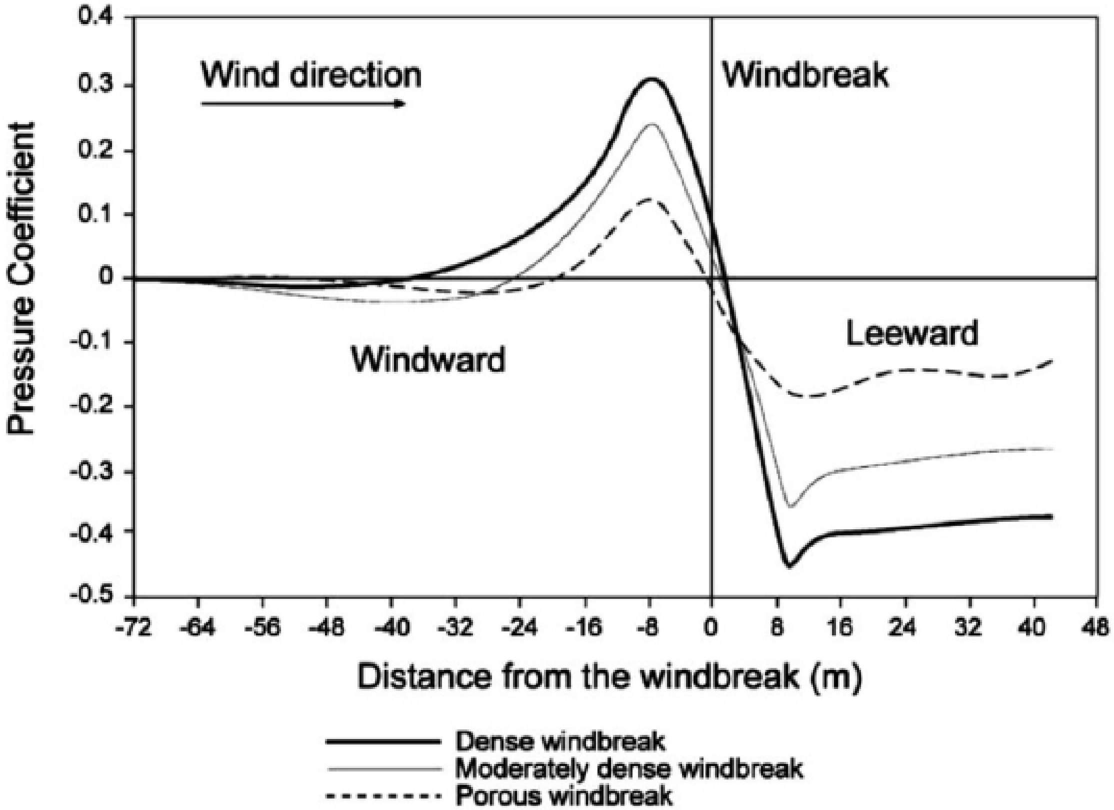

Figure 1: "Changes in the pressure coefficient at ground level windward and leeward of three windbreaks with different levels of optical density. Distances from the leeward edge of the windbreak are given as positive distances and as negative distances in the windward direction" (Brandle et al., 2004).

Height, density (or optical porosity) and orientation (perpendicular to prevailing winds) are the most important factors when assessing the effectiveness of windbreaks. The taller the vegetation the more drag on the leeward side of the barrier. Denser structures allow less wind through the interior of the windbreak. This can be in the form of increased rows, instead of a single line of trees, or could be the density of the vegetation itself. These physical attributes are important but will be less effective if these structures are not oriented perpendicular to the direction of the problem winds (Brandle et al., 2004). In assessing effects of barriers in the Midwest, Brandle et al. (2004) provides evidence that a tall medium dense coniferous windbreak, oriented perpendicular to the prevailing winds would be the most effective at reducing wind speed (Table 2).

Table 1: Percent of open area wind speed reductions in shelter at various distances (H is barrier height) windward (negative height distances) and leeward (positive height distances) of shelterbelts with different optical densities in the Midwest (Brandle et al., 2004).

Type of Windbreak	Optical Density	-25 H	-3 H	-1 H	5 H	10 H	15 H	20 H	25 H	30 H
Single row deciduous	25-30	100	97	85	50	65	80	85	95	100
Single row conifer	40-60	100	96	84	30	50	60	75	85	95
Multi-row conifer	60-80	100	91	75	25	35	65	85	90	95
Solid wall	100	100	95	70	25	70	90	95	100	100

The density of a windbreak is measured as optical porosity, as shown in Figure 2. Brandle et al. (2004) and Vacek et al. (2018) synthesized data evaluating the effectiveness of different densities of windbreaks from multiple studies across the Midwest and Europe respectively. Both papers conclude that the optimum porosity values lie somewhere between 40-50% or 40-60%. Also important is the complexity of the windbreak, number of rows, height and species differentiation which can reduce aerodynamics and slow windspeeds (Vacek et al., 2018). There is also an advantage to conifers through a decrease in optical porosity as well as providing consistent densities through all seasons.

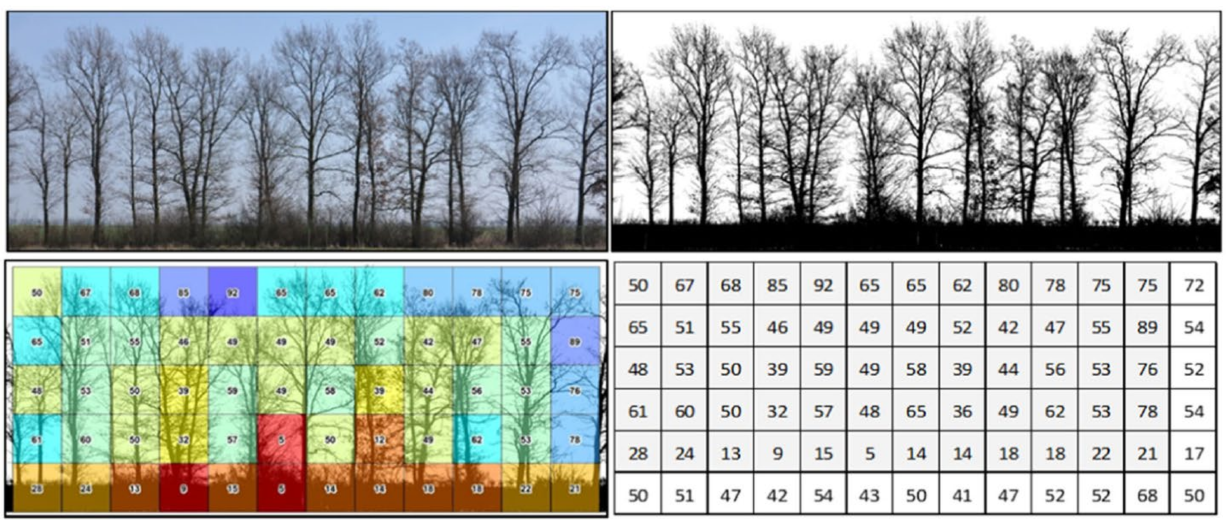

Figure 2: Example of a photograph evaluation of optical porosity, showing percent openness (Vacek et al., 2018).

When assessing the need for and designing effective windbreak structures a number of models have been developed to provide site specific estimates of potential wind erosion. This can provide land managers with forecasts on how different factors can contribute to wind erosion and potentially how to mitigate those impacts (Jarrah et al., 2020). A validation review of current models was conducted by Jarrah et al. (2020) that included correlations between the models and on the ground measurements. Below is a list of the models and how well they fit (R^2) with the on the ground measurements:

- WEQ ($R^2 = 0.96$)
- RWEQ ($R^2 = 0.91$ to 0.93)
- WEPS ($R^2 =0.71$ to 0.98)
- SWEEP ($R^2 = 0.71$ to 0.98)
- EPIC ($R^2 = 0.21$ to 0.98)
- APEX ($R^2 = 0.25$ to 0.91)
- TEAM ($R^2 = 0.93$ to 0.99)
- WEELS ($R^2 = 0.71$ to 0.82)

Each of these models provide slightly different functions and therefore may provide more or less accurate results depending on the situation (Jarrah et al., 2020). However, only TEAM and WEELS includes an input for windbreaks. Feng and Sharratt (2007, 2009) found that both SWEEP and WEPS under predicted, overpredicted and did not predict erosion events on the Columbia Plateau. However, APEX and RWEQ do appear to accurately simulate wind erosion protection in the region but only for winter wheat / spring canola and chickpea residue, respectively (Pi et al., 2020).

Many of the models tested in the inland Pacific Northwest specifically looked at how the conservation tillage practice of leaving residue on fields may reduce wind erosion. This could be a useful alternative practice in areas where, due to climatic or soil conditions, large tree establishment might be difficult, like the Columbia Plateau (Skidmore, 1986). Crop residue can reduce soil loss by reducing friction speeds at the soil surface (Feng & Sharratt, 2009; Pi et al., 2020). Pi et al. (2020) found that residue from winter wheat, spring canola, and chickpea reduced soil loss from wind erosion by 73.3, 53.4, and 60.9%, respectively. Not only could this practice be helpful in areas that are difficult to establish large trees for windbreaks, but it could also provide additional protection on fields adjacent to windbreaks. This could be most impactful in the areas of the field that are less protected by the windbreaks or when a storm event comes from an uncommon direction. See Chapter 1 (Cropping Methods: Tillage & Residue Management) for recommendations and effectiveness of this practice.

Another alternative to windbreaks are hedge rows planted in conjunction with Short Rotation Alley Cropping Systems (SRACS). These consist of fast-growing small trees or woody plants that alternate with conventional crops (Böhm et al., 2014). A study in Germany found a 50% reduction in wind speed within a 24-meter-wide alley with a black locust hedge row (Böhm et al., 2014). Like traditional tree windbreaks Böhm et al. (2014) found that orientation towards the prevailing winds is also important and if hedge rows are not oriented properly there can be an increase in windspeed. However, because these systems are smaller and quicker to establish (only about 6 months to reach effectiveness) adjustments and more complex configurations could be constructed based on site specific characteristics. One of the benefits of these systems is that the woody plants can be harvested for bioenergy and if alternating rows are harvested on a rotating basis, minimal impact to the efficiency of the windbreak is expected (Böhm et al., 2014).

Agroforestry can also be used in developing a more traditional windbreak using trees that produce fruit, nuts or wood products (Skidmore, 1986). A windbreak used for wood products would likely need to have multiple rows and a diversity of heights to maintain function as sections are harvested. For a more detailed description of agroforestry and silvopasture see Chapter 12 (Riparian Areas & Surface Water Protection). In addition to utilizing the agroforestry option in this chapter, the riparian buffers recommended would also be an effective windbreak.

Conservation Cover

The rows between permanent woody crops such as berry plants, grape vines, and fruit and nut trees can be susceptible to erosion during runoff events. Vineyards, particularly located on steep slopes, are vulnerable to erosion when the rows between vines are comprised of bare or tilled soil (Garcia et al., 2018). There has been a lot of research on soil loss in Mediterranean vineyards due to the long history of grape farming in the region. However, this research should transfer well to the orchards, vineyards, and berry farms located in the Mediterranean climate of the Pacific Northwest.

The use of herbaceous crops between rows of grape vines has been widely adopted, up to 85%, in certain regions (e.g. Alsace, Bordeaux) of France (Garcia et al., 2018). These cover crops are being used for a number of issues related to viticulture, like improvements in biodiversity and soil organic matter, water infiltration, trafficability, and erosion control (Frey, 2016; Garcia et al., 2018). These potential beneficial services to the cash crops and surrounding ecosystems need to be weighed against the potential disservices, like competition for water and nutrients. However, the disservices can be mitigated through active and adaptive management of the inter-row crops. Garcia et al. (2018) refers to these types of cover crops as “service crops” to emphasize that these beneficial services can be maximized by treating these as integral crops that need management. These potential benefits to the cash crop are in addition to the, well documented, erosion control a permanent service crop can provide (Straffelini et al., 2022).

Service crops provide direct protection against the kinetic energy of rain drops on bare soil as well as limiting the runoff potential (Garcia et al., 2018; Straffelini et al., 2022). In one study, Biddoccu (2017) found a 63% and up to 90% reduction in runoff and soil erosion, respectively. They found that the highest erosion was in vineyards that were managed with conventional tillage practices. The increased use of agricultural machinery on sloped vineyards has also been observed and measured in several studies (Straffelini et al., 2022). When conducting activities between rows, machinery can create ruts which can provide a conduit for runoff. This can be exacerbated when cultivation is done along the slope as illustrated in Figure 3.

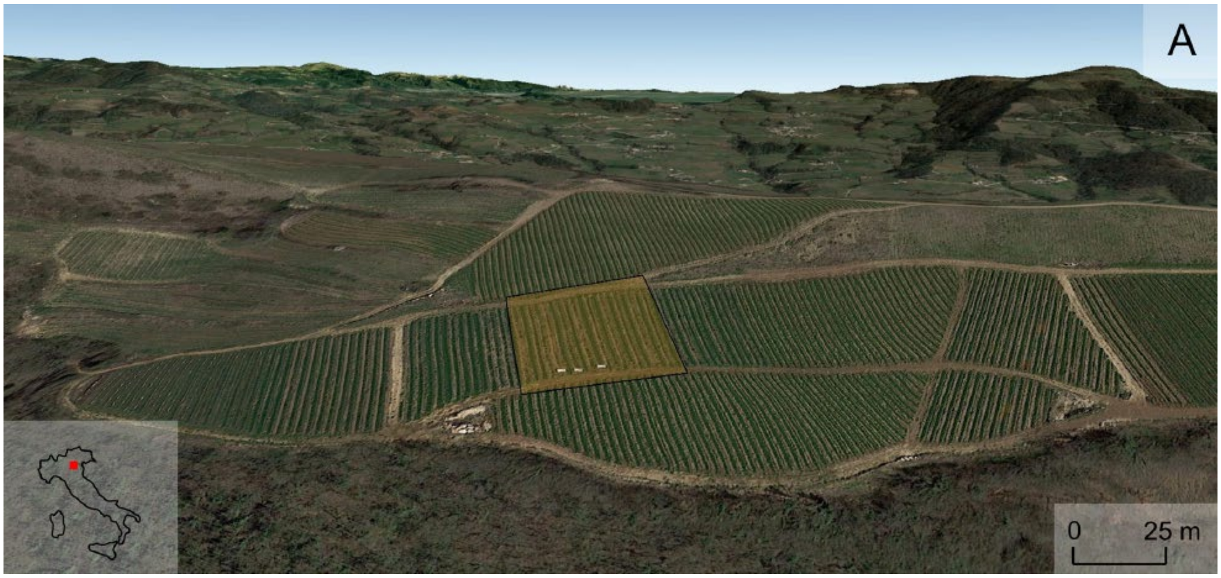

Figure 3: Google generated 3D landscape of a typical steep slope vineyard in northern Italy (Straffelini et al., 2022).

When comparing Conventional Tillage (CT) practices to Grass Cover (GC) Biddoccu (2017) measured soil losses of up to 5.7 Mg ha^{-1} in a single storm event. This was in comparison to almost no soil loss (0.009 Mg ha^{-1}) in the GC plots, see Figure 4. This graph shows that the cumulative runoff (RO cum) and resulting sediment yield (SY) was much higher in the CT fields (red line) during the rain event than the GC fields (light blue line near 0). Generally, Biddoccu (2017) found that sediment export from the tilled plots was 9 times higher than grass covered plots. Using a model approach Gomez (2003) also predicts large soil losses in olive orchards under tillage management compared to a full cover crop scenario. They also note that this is alignment with other field-based studies. This suggests that use of service crops can be effective erosion control in multiple types of woody plantations, like orchards.

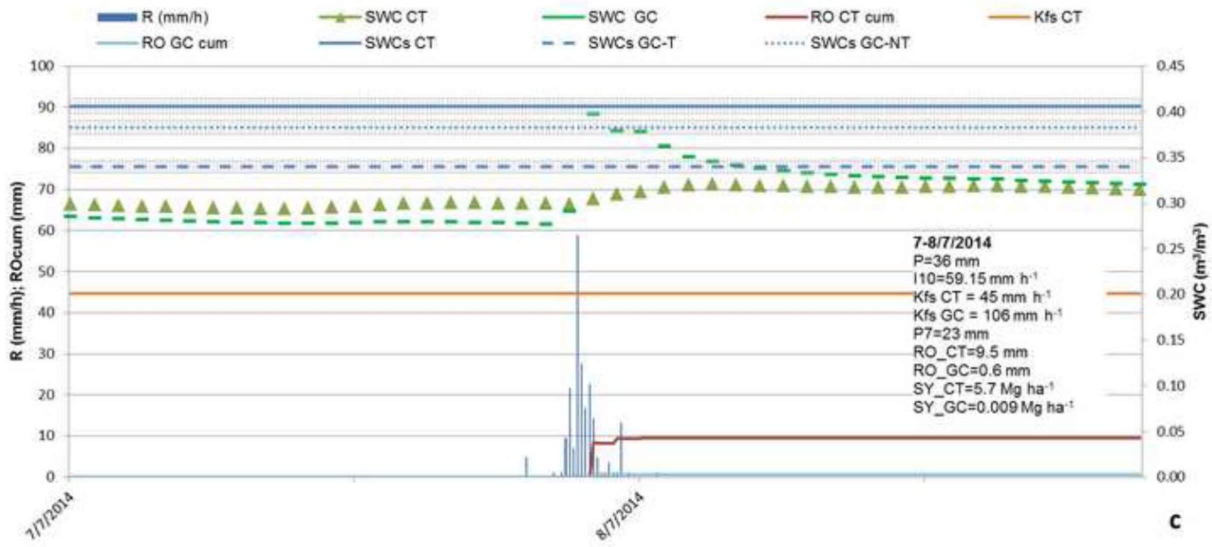

Figure 4: Runoff detection graph with pluviometer data (10 minutes step) for a rainfall event. R= rain intensity, SWC = measured volumetric soil water content (1 hour step), SWCs = reference value of saturated water content, Kfs = reference value of field-saturated hydraulic conductivity, RO cum = cumulated measured runoff, P = total event precipitation, I10 = maximum rain intensity, P7 = antecedent precipitation at 7- day step, RO= measured runoff, SY = measured sediment yield.

An additional benefit to the surface roughness a service crop creates is an increase in water infiltration during the rainy season (Garcia et al., 2018). The roots, living and dead, create macropores that allow the dispersed water to better infiltrate the soil. By slowing down the water and allowing for more infiltration the soil moisture content across the field increases and can lead to a potential increase in soil organic matter (Garcia et al., 2018). However, increase in soil moisture content is only temporary and in regions with Mediterranean climate (dry summers) there is the potential for the crops to compete for water with the cash crops (Capri et al., 2023).

The choice of service crop will determine how much water is diverted from the cash crop. Capri et al. (2023) measured evapotranspiration rates of 15 different cover crops in Northern Italy pre and post mowing by 2, 8, 17,25 days. They found that legumes used the most water prior to mowing and recovered fast than grasses and creeping plants (Figure 5). Capri et al. (2023) concludes that the dwarfing characteristics and low evapotranspiration rates of *Festuca ovina* makes it suitable for a permanent inter-row covering. They also report low evapotranspiration rates of creeping species which, with the added benefit of shallow roots, make these species ideal candidates to grow under trellis. Grapevine roots will grow under the creeping vegetation where higher soil moisture might be present. This can also be an effective method of weed control once the crop is established (Capri et al., 2023; Garcia et al., 2018).

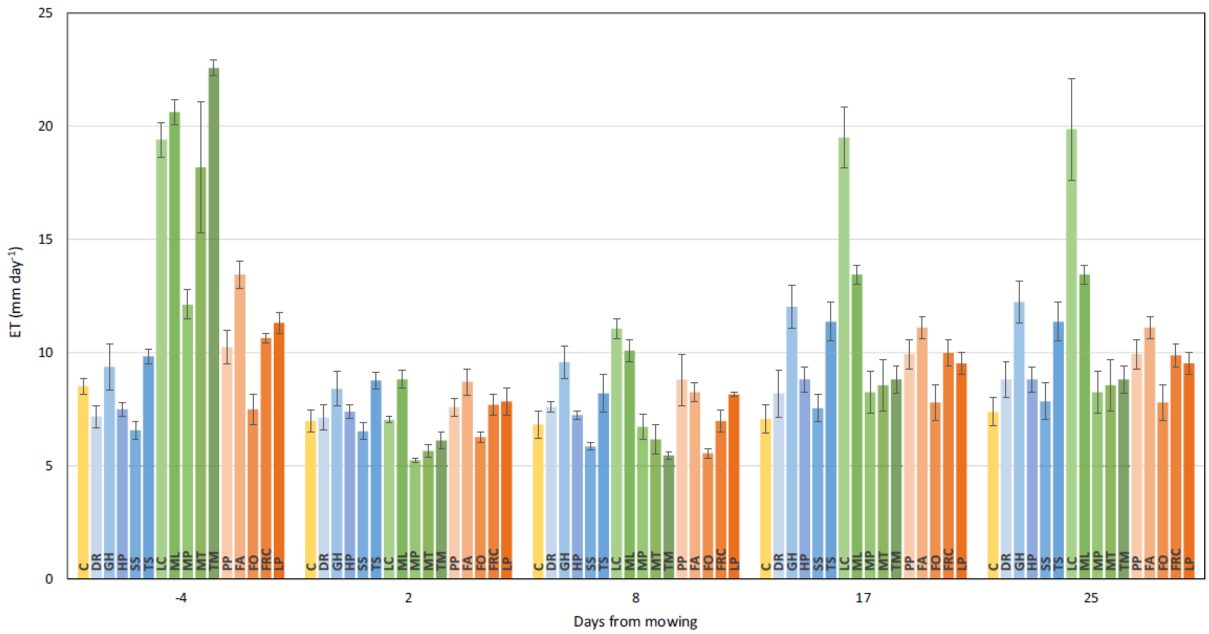

Figure 5: “Vertical bars represent the daily water use as referred to unit of soil (ET, mm day −1) for the bare soil (yellow) and all the cover crop species as divided into creeping plants (shades of blue), legumes (shades of green) and grasses (shades of orange). Evapotranspiration was measured though a gravimetric method before (i.e. − 4) and at 2, 8, 17 and 25 days after mowing. ET data are mean values ± SE (n = 4)” (Capri et al., 2023).

How service crops are managed determines how effective at preventing erosion they will be with the least amount of disservice to the cash crops. One way to mitigate the competition for water is to mow or mulch the service crop at the beginning of the dry season (Capri et al., 2023; Garcia et al., 2018). This can also limit the competition for nutrients as well (Garcia et al., 2018). The authors go on to explain that if service crop management precedes bud burst, not only will there be a reduction in competition, but also a release of inorganic nitrogen at the time of uptake by the cash crop (for more about nutrient management see Chapter 3). Using species that go dormant in the dry season will allow the crop to quickly reestablish before the rainy season. The effectiveness of the service crop will depend on how it is adaptively managed based on climatic conditions of the region/year and the different phases of the cash crop. Figure 6 provides an example of the anticipated timing and stages of a grapevines to guide a management strategy to provide ecosystem services while minimizing disservices.

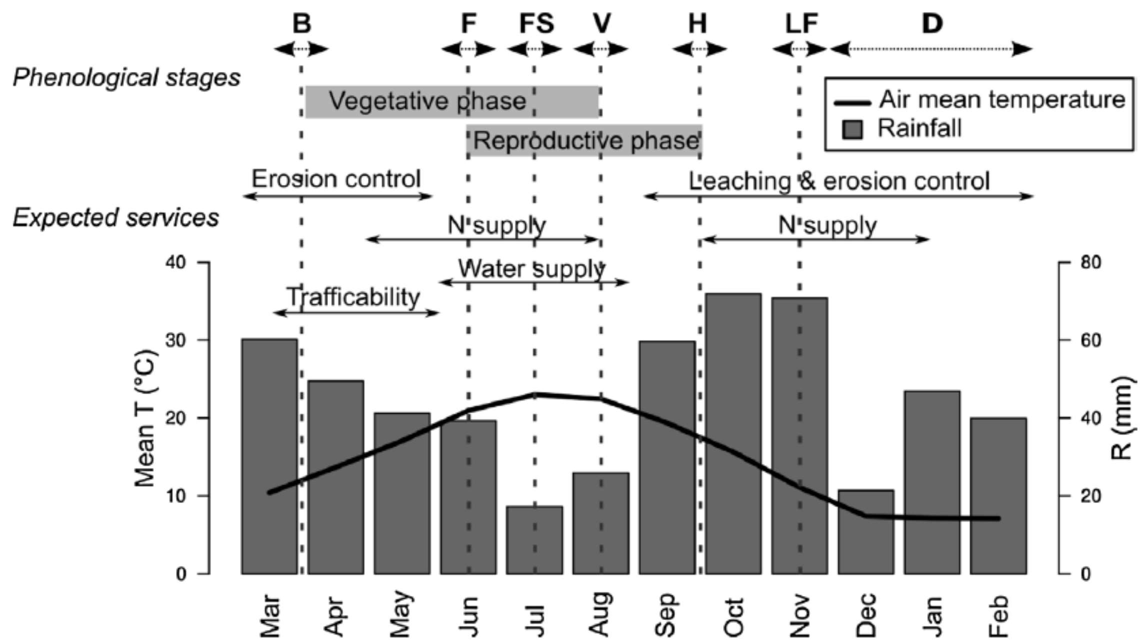

Figure 6: "Temporality of expected services in vineyard (Mediterranean region, France). The figure is structured in 3 parts: in the top the grapevine phenological stages (B: budburst, F: flowering, FS: fruit setting, V: veraison, H: harvest, LF: leaf fall, D: dormancy); in the center the ecosystem services provided by service crops in vineyards according to the period when they are expected; in the lower part Mediterranean climatic data (rainfall and mean temperature) averaged on 2005–2015 period for Roujan station (south of France)" (Garcia et al., 2018).

Contour Filter Strips

Contour farming and terracing is a long-used method for managing soil erosion on steeper sloped agricultural land (Dorren & Rey, 2004; Garrity, 1999; Helmers et al., 2012). This can be as minimal as bands of filter strips along the contours as shown in Figure 7 or as extensive as excavated terraces with vegetative berms between rows (Figure 8). These practices of manipulating the landscape along the contours are designed to intercept surface runoff, encourage infiltration, evaporation or diversion, and prevent soil erosion (Dorren & Rey, 2004; Helmers et al., 2012). The addition of vegetative strips along the contours or terraces allows for backwater above the strip to settle out the suspended sediment and retain the soil on the field (Helmers et al., 2012).

Figure 7: "Prairie strips in practice. A) Overhead photograph of multiple prairie strips at the catchment scale. Prairie strip are ∼10 m wide and cropland strips are ∼50 m wide. B) Inset photograph showing one strip with diverse prairie species planted between maize rows. Photo Credit: Iowa State University" (Dutter et al., 2023).

Figure 8: "Natural vegetative buffer strips may rapidly develop into stable agricultural terraces on steep slopes. This photo was taken seven years after the contour strips were laid out by a farmer in Claveria, Misamis Oriental Province, Mindanao, Philippines" (Garrity, 1999).

Dorren & Rey (2004) note that many institutions and academic research have provided evidence of terracing and contour farming reducing runoff and soil erosion. The authors site several studies that showed soil losses cut in half, reduced by 19 to ~ 60 tons/hectare/year and show significant reductions in runoff which can help retain soil moisture. One of the most important pieces to reducing erosion is maintaining the structure of the terrace walls and that permanent vegetation is the most cost and structurally effective method (Dorren & Rey, 2004; Garrity, 1999).

On steeper slopes more extensive excavation might be necessary to cultivate the land and prevent erosion. In the mountainous regions of the Philippines, Garrity (1999) notes that the lack of contour farming and conservation practices led to erosion rates around 60-200 tons/hectare/year. The author goes on to describe several conservation practices that were implemented and tracked in the region. Some farms used terraces with hedge rows of leguminous trees which reduced soil loss by 70-99% but tended to compete more with the cash crops for resources. To try and avoid competition some other fields were planted with native vegetation strips along the contours. This reduced soil loss by 90-97% and when combined with conservation tillage practices (see Chapter 1 for recommendations) the loss was insignificant (0.3-1.1 tons/hectare/year). These native strips require much less maintenance and tend not to compete with the adjacent annual crops. Notably, this was also found to be an indigenous practice that has been employed in this region for a long time.

In areas of gentler slopes, where full terracing is not necessary, prairie filter strips along the contours have been shown to be an effective method of sediment control (Dutter et al., 2023; Helmers et al., 2012). These perennial strips of native plants are integrated, in narrow bands, into the row crops (Dutter et al., 2023). These bands of permanent vegetation, perpendicular to the slope of the watershed, slow overland flow and help prevent channelization during runoff events. These prairie filter strips function the same as traditional filter strips by slowing down the water and creating roughness to capture sediment (see chapter 13 for effectiveness of filter strips). Helmers et al. (2012) tested the effectiveness of prairie filter strips across 12 watersheds in Iowa. Some treatments had perennial vegetation only at the foot-slope (5-10% of the total area) other sites included strips within the row crops (5-20%). This was compared to fields with only row crops and full prairie fields. The authors found that the average sediment export from the fully cropped watersheds was 3881 mg L^{-1} over the 4 years of the study. This was significantly greater than the 293 mg L^{-1} leaving the watersheds with prairie filter strips (Figure 9). The authors also note that including a no-till system with the prairie strips was highly effective (<1.1 mg L^{-1} during the crop season) and recommend including this practice in a prairie strip crop system (see Chapter 1 for no-till recommendations).

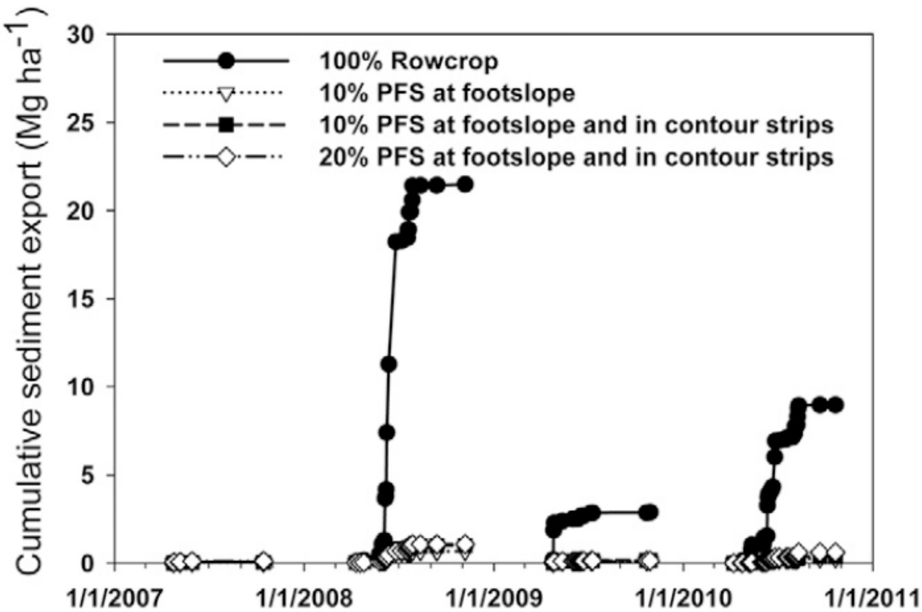

Figure 9: "Cumulative annual sediment export during growing season (April– October) for the treatments of cropland and prairie filter strips" (Helmers et al., 2012).

Cover Crops

Annual cover crops, grown after a cash crop has been harvested, have been shown to reduce runoff and soil loss (Blanco-Canqui, 2018; Dabney et al., 2001; Kaspar et al., 1996). These crops can also reduce nitrogen leaching through absorption and a reduction in runoff (See Chapter 3 for more information). Like many of the other practices listed above, cover crops increase roughness, stabilize soil with roots, allow more water to infiltrate during a storm event to help prevent soil erosion. This section will provide a quick overview of the effectiveness of cover crops, for a comprehensive review of how cover crops fit into an overall cropping strategy, see Chapter 2.

Blanco-Canqui (2018) synthesizes the current state of knowledge on cover crops impact on water quality parameters like runoff, sediment loss, nutrient losses in runoff, and nitrate leaching. They found that cover crops can increase the time to runoff initiation by 10 to 40 minutes and reduce runoff volume by 10 to 98%. However, the authors also point out that even if runoff still occurs on cropped fields, the water leaving is still less turbid due to the filtering and trapping that occurs on a vegetated field. This practice is also highly effective at reducing sediment loss, with 12 out of 13 studies showing sediment reductions of 22 to 100%. One of the key factors the author concludes is that greater biomass production is key (cover with low biomass have limited benefits). This reduction in effectiveness can occur when cover crops are planted late which may not allow enough time to accumulate enough biomass to prevent erosion during the winter months.

One method of establishing cover crops earlier in the season is to inter-seed into a cash crop, like soybean or corn, in the late summer early fall. This is to allow the cover crop time to germinate and begin accumulating biomass before the rainy and cold season starts. The effectiveness of this practice has mixed results. Kaspar et al. (2001) found some reduction in inter-rill erosion and runoff with overseeded oat and rye. Blanco-Canqui (2018) also reported on several other studies with mixed results from inter-seeding. The author suggests that this may be due to shading and poor seed to soil contact when broadcast seeding. Also, the type of species may be a factor, grasses, like cereal rye, tend to outperform other species (Blanco-Canqui, 2018). Other grasses can also be effective, Thapa et al. (2024) found 49% reduction in peak flow rates and a 43% reduction in sediment load with a cover crop of winter wheat. However, Rye is more tolerant of cold weather so might be a better candidate in colder regions or when planting late is necessary (Dabney et al., 2001)

Other conservation practices, like leaving tillage residue on the field and filter strips can also help increase the effectiveness of planting cover crops (Blanco-Canqui, 2018; Thapa et al., 2024). Multiple studies have found that using cover crops within a no-till system can reduce erosion more than conventionally tilled systems (Blanco-Canqui, 2018; Clement et al., 2024; Kaspar et al., 1996; Singh et al., 2018). In addition to conservation tillage practices, Thapa et al. (2024) also included a treatment field with filter strips when testing the effectiveness of winter cover crops. They found a reduction in peak flows and sediment load on fields with filter strips. This can be particularly helpful during the establishment of the cover crop, when the biomass is not enough to trap sediment or reduce runoff.

Capture and interception of Sediment

As mentioned in the introduction to the previous section, the practices above are designed to retain sediment in-field. However, these primary practices are not always 100% effective (especially during large storm events) or able to be fully implemented due to site specific factors. It is important that areas, in-field or directly connected to agricultural activities, that are likely to have concentrated flows are vegetated and disconnected from surface waters. The capture and interception BMPs described below are generally most effective when used in combination with one or more soil stabilization BMPs listed above.

Grassed Waterways

The effectiveness of using perennial grassed waterways to prevent gully erosion, reduce peak runoff, and sedimentation is covered in Chapter 9 (Runoff Control from Agricultural Facilities) of the VCWG. That chapter is focused on controlling and diverting clean water away from agricultural activities and preventing erosion. These same concepts apply to in-field management of concentrated flow. However, additional protections and considerations need to be considered when dealing with potentially contaminated / turbid water.

The effectiveness of a grassed waterway depends on the size, shape, and management of the area. Fiener and Auerswald (2002) found that grassed waterways with long side-slopes, flat bottoms, and were unmanaged (no mowing) performed better than the narrower v-shaped waterways. The wide unmanaged waterways showed a 90% reduction in runoff compared to 10% reduction in the narrow managed grassed waterways. The authors surmised that the difference in sediment reduction was a result of the increased infiltration in the wider waterways and less about the sediment trapping capabilities.

There is a wide range of effectiveness of this practice across all available literature. In a review Fiener and Auerswald (2017) found reporting on peak discharge reductions ranging from 5-85% and up to 95% for predicted runoff volume. The authors also report a mean sediment delivery reduction ranging from 3-35% in both field and modeling experiments. They state that the sediment trapping efficiency decreases as more runoff enters the grassed waterways from the field. This, and the reductions in peak runoff stated above, indicate that the goal of this BMP should be a reduction in peak flows which should in turn reduce sediment transport. However, due to the wide range of effectiveness in the literature surrounding this practice it is important that the outlet of the grassed waterway not be to surface water. Instead, the outlet should be directly tied to an additional BMP like a filter strip or vegetated treatment area (described below).

Filter Strips

The effectiveness of using perennial filter strips to capture sediment (nutrients and pathogens as well) is covered in Chapter 12 (Riparian Areas & Surface Water Protection) of the VCWG. This chapter includes filter strips as an option for either the inner or outer zone for some alternative configurations of the riparian management zones. Even though the focus of chapter 12 is on riparian areas the same concepts apply to other areas where concentrated flow and sediment transport may occur. For a detailed discussion of filter strips see Chapter 12, however some key points about this BMP are described below.

Vegetated filter strips trapped 53-99% of sediment in the experimental studies reviewed in Chapter 12. By increasing the width of the filter strips to 5-9m wide Robbinson et al. (1996), Gharabaghi et al. (2006), and Dosskey et al. (2007) estimated a 75-95% reduction in sediment. Helmers et al. (2005) and Dosskey et al. (2002) noted that locating filter strips according to micro-topography, in areas where concentrated flows are likely to occur, is more effective at dispersing runoff and increasing infiltration. The authors also suggest orienting row crops along contours and not farming uphill-downhill will inhibit flow into swales and increase the effectiveness of filter strips at the end of fields. Gilley et al. (2000) found that combining grass hedges with no-till cropping decreased the sediment loads leaving the field compared with traditional tillage practices. Lee et al. (2003) estimated 13 times less sediment exported from a mixed grass-woody strip compared to only a grassed filter strip. These additional features of the filter strips and upland practices will increase the efficiency of this BMP.

Vegetative Treatment Area

The effectiveness of using perennial vegetative treatment areas to capture sediment (nutrients and pathogens as well) is covered in Chapter 9 (Runoff Control from Agricultural Facilities) of the VCWG. This chapter focuses on diverting water around agricultural practices, however the same principles assessed apply to runoff from agricultural fields with a potential increase in area and maintenance when implementing this BMP.

References

Annotated Bibliography

Windbreaks

1) Böhm, C., Kanzler, M., & Freese, D. (2014). Wind speed reductions as influenced by woody hedgerows grown for biomass in short rotation alley cropping systems in Germany. Agroforestry Systems, 88, 579-591.

This paper investigates the potential of short rotation alley cropping systems (SRACS) as effective windbreaks on agricultural sites in Germany. The study reveals that hedgerows of fast-growing trees significantly reduce wind speed on crop alleys, this is closely connected to the wind direction and the orientation of the hedgerows. The efficiency of windbreaks is influenced by the spatial arrangement, width of hedgerows, and their orientation, with key findings suggesting that hedgerows oriented against the prevailing wind direction result in the maximum shelter effect. The authors highlight the importance of understanding the specific site conditions and agricultural landscapes to design optimal SRACS for effective wind protection. If designed properly, hedgerows are potentially effective windbreaks despite the relatively low height.

2) Brandle, J. R., Hodges, L., & Zhou, X. H. (2004). Windbreaks in North American agricultural systems. Agroforestry Systems, 61, 65-78.

This paper provides some historical background of windbreaks, from their origins in the mid-1400s in Scotland to extensive usage in different parts of the world, including the United States, Canada, Australia, and several developing countries. The authors also provide insights into the wind flow alteration around and through the windbreaks, the effect on microclimate changes, and the influences of windbreaks on plant growth and development. It explains the concept of "coupling" in plant response to shelter and discusses direct and indirect impacts of wind on various plant processes.

3) Feng, G., & Sharratt, B. (2007). Validation of WEPS for soil and PM10 loss from agricultural fields within the Columbia Plateau of the United States. *Earth Surface Processes and Landforms*, *32*(5), 743-753.

4) Feng, G., & Sharratt, B. (2009). Evaluation of the SWEEP model during high winds on the Columbia Plateau. *Earth Surface Processes and Landforms*, *34*(11), 1461-1468.

5) Jarrah, M., Mayel, S., Tatarko, J., Funk, R., & Kuka, K. (2020). A review of wind erosion models: Data requirements, processes, and validity. Catena, 187, 104388.

This review is a comparison of various wind erosion models, outlining their validation, databases, and processes. The authors examined validation studies of the selected models by examining model predictions compared with field observations and wind tunnel experiments.

The Wind Erosion Equation (WEQ), despite being one of the oldest models, has surprisingly few validation studies. The Revised Wind Erosion Equation (RWEQ) was found to have mixed results, with validation studies reporting R^2 values ranging from 0.01 to 0.81.

The Wind Erosion Prediction System (WEPS) and Single-event Wind Erosion Evaluation Program (SWEEP) have been extensively evaluated throughout the United States, Europe, Africa, China, and South America. Both models were found to under-predict or not predict some relatively small erosion events on soils covered with plants, residues, or had a high surface roughness.

Texas Erosion Analysis Model (TEAM) was noted for having additional factors no other wind erosion model has, such as relative humidity, wind gust factor, and a dynamic length factor. Overall, the paper provided a detailed comparison of major wind erosion models, focusing on their validation, databases, and how the erosion processes were modeled.

6) Larney, F. J., Cessna, A. J., & Bullock, M. S. (1999). *Herbicide transport on wind-eroded sediment* (Vol. 28, No. 5, pp. 1412-1421). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

7) Pi, H., Webb, N. P., Huggins, D. R., & Sharratt, B. (2020). Critical standing crop residue amounts for wind erosion control in the inland Pacific Northwest, USA. Catena, 195, 104742.

This study evaluated the impact of standing residue on soil wind erosion in the inland Pacific Northwest (iPNW) and tested the performance of the Agricultural Policy/Environmental eXtender (APEX) and Revised Wind Erosion Equation (RWEQ) models in simulating soil loss for different crop types. The research found that standing winter wheat, spring canola, and chickpea residue provided significant protection against wind erosion at typical residue densities. It was observed that soil loss was reduced by 73.3%, 53.4%, and 60.9% for winter wheat, spring canola, and chickpea, respectively. Winter wheat was the most effective at preventing soil loss. However, the soil surface was found to be significantly at risk from wind erosion when residue densities of the three crop types were less than 50% of the typical production amounts.

The study also revealed a link between the orientation of the crop rows relative to the wind direction and the reduction of soil loss, with a decrease in soil loss with rows perpendicular to the wind direction. The APEX model adequately simulated winter wheat and spring canola residue protection, while the RWEQ model appeared better represented chickpea residue effects. The results suggest that different crops and residue structures can have varied impacts on wind erosion and that there is a need for site-specific evaluation of critical residue amounts for controlling wind erosion. The study emphasizes the importance of considering model accuracy and crop-specific thresholds for wind erosion management and provides key insights for informing crop residue management for wind erosion control in the iPNW.

8) Sharratt, B., Feng, G., & Wendling, L. (2007). Loss of soil and PM10 from agricultural fields associated with high winds on the Columbia Plateau. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *32*(4), 621-630.

9) Skidmore, E. L. (1986). Wind erosion control. Climatic Change, 9(1-2), 209-218.

This paper examines the problem of wind erosion and its impacts on soil fertility, air pollution, and agricultural productivity by looking at some of the original research from

the 1940s through the 1970s. The author discusses how wind erosion processes remove the most fertile portion of the soil, pollutes the air, and reduces seedling survival and growth. How the prevalence of wind erosion is worse in arid and semi-arid climates due to lose, dry soils, smooth surfaces devoid of vegetative cover, large fields, and strong winds. Skidmore also includes a simple wind erosion equation, from an earlier paper, which outlines principles for controlling wind erosion, such as stabilizing erodible surfaces with various materials, producing a rough cloddy surface, reducing field width with barriers, and establishing sufficient vegetative cover.

10) Skidmore, E. L. (2000, October). Air, soil, and water quality as influenced by wind erosion and strategies for mitigation. In *Second international symposium of new technologies for environmental monitoring and agro-applications proceedings* (pp. 216-221).

11) Tuo, D., Xu, M., Gao, L., Zhang, S., & Liu, S. (2016). Changed surface roughness by wind erosion accelerates water erosion. *Journal of Soils and Sediments*, *16*, 105-114.

12) US Department of Agriculture. (2020). Summary Report: 2017 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology.

13) Vacek Z., Řeháček, D., Cukor, J. et al. (2018). Windbreak Efficiency in Agricultural Landscape of the Central Europe: Multiple Approaches to Wind Erosion Control. Environmental Management, 62, 942–954.

This study evaluates the effects of three windbreak types on wind erosion control in the central part of the Czech Republic. It assesses the structural diversities, wind-speed reduction, and optical porosities of the windbreaks and how these characteristics impact wind erosion control. The results showed a significant correlation between optical porosity and wind-speed reduction, especially in the lower part of the windbreak and the locations with multiple rows of trees. The windbreak efficiency was also found to depend on the tree dominant height and structural indices. This highlights the importance of windbreaks in reducing wind speed, protecting soil against wind erosion, improving microclimate, increasing biodiversity, and supporting agricultural production potential. The authors also note that wood production is possible with a continual renewal approach to a multi-canopy windbreak. The findings emphasize the need for proper establishment and maintenance of windbreaks to provide long-lasting positive effects for the environment and local farms.

14) Van Ramshorst J.G.V., Siebicke L., Baumeister M, Moyano F.E., Knohl A., Markwitz C. (2022). Reducing Wind Erosion through Agroforestry: A Case Study Using Large Eddy Simulations. Sustainability, 14(20):13372.

The focus of this study is on the potential of alley cropping agroforestry systems to reduce wind erosion in dry and sandy regions, based on a case study in Germany. The study used wind measurements and Large Eddy Simulations to estimate the reduction in wind speed and potential wind at the study site. The distance between the tree strips was found to have a significant impact on wind speed and potential wind erosion, with shorter distances leading to higher and more stable reduction. Tree strip orientation

relative to the dominant wind direction was found to have a strong influence on wind speed and potential wind erosion reduction (up to a 92% reduction). Tree height and the density were also observed to play a role in wind speed reduction and potential wind erosion.

The authors concluded that for optimal protection, the tree strips should be oriented perpendicular to the dominant wind direction, or at least diagonally. They recommended distance between tree strips of ≤48 m, with dense tree strips of 2m height. Taller tree heights can further increase and stabilize the reduction of wind erosion for wind directions perpendicular to the tree strips, especially at higher wind speeds. The authors contend that a well-designed alley cropping agroforestry system can reduce wind erosion by more than 80%.

Conservation Cover

15) Capri, C., Gatti, M., Fiorini, A., Ardenti, F., Tabaglio, V., & Poni, S. (2023). A comparative study of fifteen cover crop species for orchard soil management: water uptake, root density traits and soil aggregate stability. Scientific Reports, 13(1), 721.

    Using a randomized block design, this study aimed to identify cover crops for vineyard and orchard floor management based on evapotranspiration (ET) rates, root growth patterns, and soil aggregate stability potential. Fifteen species of grasses, legumes, and creeping plants were evaluated along with a bare soil control in a randomized block trial using above ground pots. ET was assessed through a gravimetric method, and above-ground dry biomass, root length density, root dry weight, and root diameter class length were measured.

    The findings revealed that legumes had the highest ET rates due to fast development after sowing, while grasses showed lower ET rates but required high water use in proportion to leaf area index (LAI). Legumes and grasses demonstrated variation in their water use reduction after mowing, suggesting a linear decrease in water use up to a certain LAI threshold. *F. ovina* (grass) stood out as having the lowest ET due to its "dwarfing" characteristics, making it suitable for permanent inter-row covering and mulch source. Creeping species confirmed their potential for under-vine grassing, assuring rapid soil coverage, lowest ET rates, and shallow root colonization.

    The study also highlighted the influence of cover crop species on soil aggregate stability and root traits, specifically *G. hederacea* and *L. corniculatus*. These species as well as other shallow, thick root plants could help with soil organic carbon, water infiltration, and soil and nutrient losses through erosion.

16) Gómez, J. A., Battany, M., Renschler, C. S., & Fereres, E. (2003). Evaluating the impact of soil management on soil loss in olive orchards. Soil use and management, 19(2), 127-134.

17) Garcia, L., Celette, F., Gary, C., Ripoche, A., Valdés-Gómez, H., & Metay, A. (2018). Management of service crops for the provision of ecosystem services in vineyards: A review. Agriculture, Ecosystems & Environment, 251, 158-170.

In this literature review the authors explore the role of service crops in vineyards and their impact on ecosystem services and disservices. They highlight that service crops (inter-row cover crops) have the potential to increase soil organic matter and fertility, reduce runoff and erosion processes, control weeds, regulate pests and diseases, supply water, and improve soil biodiversity.

However, the association of service crops with grapevines can also generate disservices and impair grape production, specifically competition for soil resources with grapevines. The authors propose a framework for the management of service crops in vineyards. They stress that vine growers need to find the balance between services and disservices based on local soil and climate conditions, grape production objectives, and the nature and temporality of the ecosystem services for vine development.

The implementation of service crops has been recognized for providing effective erosion control measures in vineyards. These crops protect the soil from water and wind erosion, enhancing the stability of soil aggregates and protecting them from the impacts of raindrops. Notably, they aid in reducing soil crusting and sealing, factors that contribute to erosion. Various studies have demonstrated that the presence of service crops, such as *S. cereale* and *B. distachyon*, can significantly decrease soil loss by water erosion.

The authors also discuss the importance of providing management options such as the choice of species, their spatial distribution within the vineyard, the timing of installation, maintenance, and destruction of service crops. The authors also suggest using adaptive strategies and annual adjustments to improve the sustainability of vineyards, emphasizing the importance of indicators of grapevine stress to coordinate vine and service crop management, along with soil resources.

18) Marques, M. J., García-Muñoz, S., Muñoz-Organero, G., & Bienes, R. (2010). Soil conservation beneath grass cover in hillside vineyards under Mediterranean climatic conditions (Madrid, Spain). Land Degradation & Development, 21(2), 122-131.

19) Monteiro, A., & Lopes, C. M. (2007). Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. Agriculture, ecosystems & environment, 121(4), 336-342.

This three-year experiment compared the effects of three treatments: soil tillage (control), permanent resident vegetation, and permanent sown cover crop on various aspects of vineyard dynamics and performance. The findings revealed that the treatments induced changes in weed dynamics, with the vegetative treatments leading to higher water use during spring and a significant reduction in vine vegetative growth compared to soil tillage. In the vegetative treatments the grapevine yield and berry sugar accumulation were not affected, acidity was reduced, and berry skin total phenols and anthocyanins increased. The findings demonstrated that cover cropping, particularly permanent resident vegetation, can be a beneficial practice, providing stable grapevine performance while positively influencing certain aspects of grape and wine quality.

20) Ruiz-Colmenero, M., Bienes, R., & Marques, M. J. (2011). Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil and Tillage Research, 117, 211-223.

21) Straffelini, E., Pijl, A., Otto, S., Marchesini, E., Pitacco, A., & Tarolli, P. (2022). A high-resolution physical modelling approach to assess runoff and soil erosion in vineyards under different soil managements. Soil and Tillage Research, 222, 105418.

The research paper examines the impact of steep-slope viticulture and the threat that runoff and soil erosion pose significant to vineyards, especially with the increasing frequency of heavy rainfall due to climate change. The preference for modern viticulture to use mechanical tillage techniques accelerates surface erosion and underscores the need for sustainable management practices to mitigate these issues. The researchers investigated the behavior of four inter-row steep slope vineyard practices in generating runoff and soil erosion due to heavy rainfall using a physically based model (SIMWE) that employed easily measurable and cost-effective input data. The study successfully validated the outcomes based on field observations, highlighting the potential of this modeling approach as a low-cost alternative to expensive in-field quantifications.

The findings reveal that a single tillage (ST) is effective in mitigating soil erosion in steep slope vineyards compared to grassed but untilled management (RF). Additionally, the use of a mix of nectariferous herbaceous species (NF) is more effective at erosion mitigation, compared to the RF treatment, with the additional positive effects on soil preparation and biodiversity. Continuous tillage (CT) was found to produce the highest concentration of sediment in runoff.

The research further demonstrates the potential of new technologies in remote sensing, particularly the use of UAV-SfM, and high-resolution data for modeling applications. This enabled the researchers to assess the impact of mechanization in vineyards, notably identifying maximum values of a connectivity index, focusing on runoff pathways created by tire tracks. These pathways were the main driver the authors noted for the higher sediment concentrations in the RF treatments.

Contour Filter Strips

22) Chen, D., Wei, W., & Chen, L. (2017). Effects of terracing practices on water erosion control in China: A meta-analysis. Earth-Science Reviews, 173, 109-121.

23) Dorren, L., & Rey, F. (2004). A review of the effect of terracing on erosion. In Briefing Papers of the 2nd SCAPE Workshop (pp. 97-108). C. Boix-Fayons and A. Imeson.

24) Dutter, C., Damiano, L. A., Niemi, J., Miller, B. A., Schulte, L. A., Liebman, M., ... & McDaniel, M. D. (2023). Contour prairie strips affect adjacent soil but have only slight effects on crops. Field Crops Research, 296, 108905.

25) Garrity, D. P. (1999). Contour farming based on natural vegetative strips: expanding the scope for increased food crop production on sloping lands in Asia. Environment, Development and Sustainability, 1(3), 323-336.

The paper explores the adoption and impact of contour farming based on natural vegetative strips (NVS) as a conservation farming system by smallholder farmers in the

Philippines. The farming system involves the use of natural vegetative to form terraces to conserve soil and sustain yields on steeply sloping cropland. Farmers adapted contour hedgerow farming practices into the simpler NVS system resulting in gradually increasing yields with an estimated benefit of 0.5 t/ha/crop.

Additionally, the authors also point out the importance of using conservation tillage practice in combination with NVS to minimize soil loss. In a recently completed study the authors note that ridge tillage reduced erosion by 49-58%, NVS by 90-97% and when combined, soil loss was minimal.

26) Helmers, M. J., Zhou, X., Asbjornsen, H., Kolka, R., Tomer, M. D., & Cruse, R. M. (2012). Sediment removal by prairie filter strips in row-cropped ephemeral watersheds. Journal of Environmental Quality, 41(5), 1531-1539.

This study evaluated the effectiveness of prairie filter strips (PFS) in trapping sediment from agricultural runoff in central Iowa. The research aimed to assess the impact of different PFS treatments on sediment export from croplands. The study found that incorporating PFS at the foot slope position in annual row crop systems under a no-till system can effectively reduce sediment loss during storm events.

This 4-year experimental study evaluated four different treatments (3 PFS treatments, 1 without PFS) with varying size and location. All the mitigation treatments had 10% of the area converted to natural prairie conditions at the toe slope of the watershed, compared to a traditional row crop planted across the watershed (all were under a no-till system of harvest). On average the PFS treatments had a 96% sediment trapping efficiency for the 4-year study period (100% cropped = 3881 mg L^{-1}, PFS watersheds = 293 mg L^{-1}). There were no significant differences between the PFS treatments, the treatments with PFS only at the base of the watershed performed as well as the treatments with upslope contour strips. This suggest that incorporating PFS at the foot slope position of annual row crop systems provides an effective approach to reducing sediment loss in runoff from agricultural watersheds under a no-till system.

Cover Crops

27) Blanco-Canqui, H. (2018). Cover crops and water quality. Agronomy Journal, 110(5), 1633-1647.

This review synthesizes the current state of knowledge on Cover Crops (CC) impacts on water quality parameters like runoff, sediment loss, nutrient losses in runoff, and nitrate leaching. CCs can increase the time to runoff initiation by 10 to 40 minutes and reduce runoff volume by 10 to 98%. CCs are also highly effective at reducing sediment loss, with 12 out of 13 studies showing sediment reductions of 22 to 100%.

Several factors influence CC effectiveness, including climate, soil texture, CC biomass production, planting/termination timing, CC species, and tillage management. Greater CC biomass production is key, as CCs with low biomass have limited benefits. Grass CCs like cereal rye tend to outperform other species. No-till systems also appear to enhance the water quality benefits of CCs compared to tilled systems.

The effectiveness in reducing sediment loss is attributed to several mechanisms:

1. The canopy and residues of cover crops provide protective cover, intercepting raindrops and reducing their erosive impact on the soil surface. This protective cover helps prevent the rapid dislodgement of soil aggregates and the release of fine soil particles, which are prone to being transported by runoff water. Additionally, settling of detached fine particles can lead to surface sealing, reducing water infiltration and increasing runoff sediment transport. By safeguarding the soil surface from erosive impacts, cover crops effectively reduce sediment loss.
2. Cover crops, by reducing the impact of raindrops and the formation of rills, lower runoff velocity, which in turn diminishes the capacity of runoff to transport sediment and nutrients. This reduction in runoff velocity leads to enhanced sediment deposition, further contributing to the reduction of sediment loss.
3. Cover crops aid in filtering runoff, effectively reducing sediment concentration, and facilitating the removal of sediment from runoff water. Dense cover crops that uniformly blanket the soil are particularly effective at filtering runoff. This filtering ability results in reduced sediment loss, with studies showing that cover crops reduce sediment loss in the majority of cases.

Cover crops play a role in improving soil properties that affect soil erodibility, such as wet soil aggregate stability and soil organic matter concentration, both of which contribute to reducing sediment loss. Increased wet soil aggregate stability, facilitated by cover crops, helps protect and store organic matter and nutrients, thus reducing soil erosion and enhancing soil fertility. The authors summarize that cover crops, in most cases, can be highly effective in reducing sediment loss through various mechanisms, including providing protective cover, reducing runoff velocity, filtering runoff, and improving soil properties.

28) Clement, T., Bielders, C. L., & Degré, A. (2024). How much do conservation cropping practices mitigate runoff and soil erosion under Western European conditions: A focus on conservation tillage, tied ridging and winter cover crops. Soil Use and Management, 40(2), e13047.

29) Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis, 32(7-8), 1221-1250.

This literature review is an in-depth analysis of the impacts of cover crops in cropping systems, focusing on their effects on soil and water quality. Cover crops have been found to improve soil quality by enhancing biological, chemical, and physical properties, such as organic carbon content, cation exchange capacity, aggregate stability, and water infiltrability.

The authors also highlight how cover crops reduce sediment production from cropland by intercepting the kinetic energy of rainfall and by decreasing the amount and velocity of runoff. Through their root systems and aboveground biomass, cover crops help to stabilize the soil by reducing the impact of raindrops, which in turn, minimizes soil detachment and aggregate breakdown. This action protects the soil from erosion and

helps to maintain soil structure and fertility. The increase in biomass production by cover crops results in greater transpiration and water infiltration into the soil, thus decreasing runoff and potential erosion to a greater extent. The protective cover provided by these crops also reduces wind erosion, particularly when crop residues remain on the soil surface.

30) Kaspar, T. C., Radke, J. K., & Laflen, J. M. (2001). Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. Journal of Soil and Water Conservation, 56(2), 160-164.

This research paper examines the effectiveness of oat and rye cover crops in reducing erosion in no-till soybean crops in Iowa. Oat and rye cover crops were over-seeded into pre-harvest soybeans in August 1995, 1996, and 1997 on a sloping site. Rainfall simulators were used to generate precipitation. Measurements of infiltration, runoff, and inter-rill erosion were taken in April 1996, 1997, and 1998. The authors found that oat and rye cover crops had no effect on infiltration and erosion in 1996. However, in 1997, both oat and rye cover crops reduced inter-rill erosion, and in 1998, only rye increased infiltration and reduced inter-rill erosion and runoff. The authors note that this was likely because the inter-seeded oat crop died during the winter while the rye survived.

The study also found that untracked inter-rill had less inter-rill erosion and runoff, and more infiltration than tracked inter-rill. It appears that wheel traffic had no measurable effect on rill erosion at these sites. The authors emphasize that cover crops can increase infiltration and reduce runoff volumes and thereby limit sediment transport. Previous studies referenced also indicate the potential of cover crops in reducing annual soil loss and the importance of cover crop management systems in the corn/soybean rotation in the northern Corn Belt.

31) Singh, G., Schoonover, J. E., & Williard, K. W. (2018). Cover crops for managing stream water quantity and improving stream water quality of non-tile drained paired watersheds. Water, 10(4), 521.

This study evaluated the impacts of cover crops on stream water quality in non-tiled drain cropland in Illinois. This was a paired watershed design focusing on no-till corn-soybean rotation with winter cover crops cereal rye and hairy vetch. Large storm events were sampled for total suspended solids (TSS), nitrate-N (NO3 -N), ammonia-N (NH4 -N), dissolved reactive phosphorus (DRP), and total discharge to evaluate the water quality impacts of cover crops. The study found that during the treatment period, cover crops reduced TSS and discharge by 33% and 34%, respectively, in the cover crop treatment watershed. However, the concentrations of NO3 -N, NH4 -N, and DRP did not decrease, potentially due in part to the use of a nitrogen fixing legume as a cover crop.

32) Singh, P., Wu, J. Q., McCool, D. K., Dun, S., Lin, C. H., & Morse, J. R. (2009). Winter hydrologic and erosion processes in the US Palouse region: Field experimentation and WEPP simulation. Vadose Zone Journal, 8(2), 426-436.

33) Thapa, A., Aryal, N., Reba, M. L., Teague, T. G., Payne, G. K., & Pieri, A. (2024). Effects of Cover Crop and Filter Strips on Sediment and Nutrient Loads Measured at the Edge of a Commercial Cotton Field.

This study involved the evaluation of the effectiveness of using cover crops and filter strips on sediment and nutrient loss at the edge of paired commercial cotton fields. The cover crops included winter wheat, black oat, and ryegrass seeded in the winter fallow period, with filter strips of switchgrass transplanted around the drainage pipe at the edge of the treatment field. The monitoring system measured discharge and collected composite water samples from rainfall and irrigation runoff events, analyzing them for phosphate (PO4-P), total phosphorus (TP), nitrate (NO3-N), ammonium (NH4-N), total nitrogen (TN), and suspended sediment concentrations. The data collected from 2015 to 2020 compared 66 runoff events (Precipitation) between the control and cover crop treatment fields during the non-growing season and indicated significant reductions in median peak flow and sediment loads. Similarly, a comparison of 55 runoff events between the control and filter strip treatment fields during the growing season (Irrigation) found significant reductions in runoff depth, peak flow rate, and sediment loads.

The cover crops achieved reductions in runoff depth, peak flow rate, sediment, total phosphorus (TP), and total nitrogen (TN) loads by 30%, 49%, 43%, 4%, and 7%, respectively. Likewise, the filter strips reduced runoff depth, peak flow rate, sediment, TP, and TN loads by 36%, 49%, 56%, 15%, and 21%, respectively. The nutrient results were non-significant, however the authors indicate that other results demonstrate the potential for reducing runoff depth, peak flow rate, and sediment load following the implementation of cover crops and filter strips at the commercial field scale.

Grassed Waterways

See Chapter 9 (Runoff Control from Agricultural Facilities) for additional citations.

34) Fiener, P., & Auerswald, K. (2003). Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. *Journal of Environmental Quality*, *32*(3), 927-936.

35) Fiener, P., & Auerswald, K. (2017). Grassed waterways. *Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation*, *59*, 131-150.

Filter Strips

See the annotated bibliography of Chapter 12 (Riparian Areas and Surface Protection) for summaries of the studies below and additional citations.

36) Dosskey, M.G.G., Helmers, M.J., Eisenhauer, D.E., Franti, T.G., and Hoagland, K.D. 2002. Assessment of concentrated flow through riparian buffers. Journal of Soil and Water Conservation. 57: 336-343.

37) Dosskey, M.G.G., Hoagland, K.D., and Brandle, J.R. 2007. Change in filter strip performance over ten years. Journal of Soil and Water Conservation. 62: 21-32.

38) Gharabaghi, B., Rudra, R.P., and Goel, P.K. 2006. Effectiveness of vegetative filter strips in removal of sediments from overland flow. Water Qual. Res. J. Canada. Vol. 41, No 3. pp 275-282.

39) Gilley, J.E., Eghball, B., Kramer, L.A., and Moorman, T.B. 2000. Narrow grass hedge effects on runoff and soil loss. Journal of Soil and Water Conservation. 55: 190-196.

40) Helmers, M.J., Eisenhauer, D.E., Dosskey, M.G.G., Franti, T.G., and Brothers, J.M. 2005. Flow pathways and sediment trapping in a field-scale vegetative filter. Transactions of the American Society of Agricultural Engineers. 48: 955-968.

41) Lee, K-H., Isenhart, T.M., and Schultz, R.C. 2003. Sediment and nutrient removal in an established multi-species riparian buffer. Journal of Soil and Water Conservation. 58: 1-8.

42) Robinson, C.A., Ghaffarzadeh, M., and Cruse, R.M. 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. Journal of Soil and Water Conservation. 51: 227-230.

Vegetative Treatment Areas

See Chapter 9 (Runoff Control from Agricultural Facilities) for citations.

General Erosion

43) De Baets, S., Poesen, J., Gyssels, G., & Knapen, A. (2006). Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology, 76(1-2), 54-67.

44) Fan, C. C., & Su, C. F. (2008). Role of roots in the shear strength of root-reinforced soils with high moisture content. Ecological engineering, 33(2), 157-166.

45) Zuazo, V. H. D., & Pleguezuelo, C. R. R. (2009). Soil-erosion and runoff prevention by plant covers: a review. Sustainable agriculture, 785-811.

Chapter 5 Appendix Part B: Implementation Considerations (Sediment Control: Soil Stabilization & Sediment Capture (Vegetative))

Introduction

This section describes factors related to the implementation of best management practices (BMPs) for soil stabilization and sediment capture in Washington State (WA). This section focuses on factors that apply to the design, construction, and maintenance of BMPs for vegetative sediment capture and soil stabilization and is meant to guide producers when deciding if these BMPs are appropriate for their land. General information is provided below on costs and benefits along with a discussion of the barriers and incentives for implementation. Tables throughout the document provide specific information on the following BMPs:

- Multi-Row Windbreaks
- Hedgerows
- No-Till
- Conservation Cover
- Cover Crops
- Filter Strips
- In-field Contour Filter Strips
- Terrace Filter Strips
- Grassed Waterways
- Vegetative Treatment Areas

This information is provided to support producers with adopting BMPs that protect water quality. A significant portion of this chapter can be tied to other Voluntary Clean Water Guidance for Agriculture chapters, which are referenced for more details. Information was gathered through a literature review of guidance materials provided by the Natural Resources Conservation Service (NRCS), WA Conservation Districts (CD), and other agencies.

Adoption of Soil Stabilization & Sediment Capture (Vegetative) Systems in Washington State

Soil Stabilization and sediment capture BMPs are used in various ways throughout WA depending on soil and climatic conditions. Each producer's implementation process will be unique depending on their preferences and site conditions. This section summarizes implementation-related challenges and benefits and provides detailed considerations for the implementation of each BMP.

Challenges

Soil stabilization and sediment capture BMPs may not be suitable to all operations or crop types. Practices that are appropriate for protecting water quality for any given operation depend on farm-specific conditions, producers' priorities, crops, and production methods. Farmers switching to conservation tillage, particularly no-till, may have a greater reliance on chemical-based management measures to control weeds.

Benefits

Soil stabilization and sediment capture BMPs are beneficial due to their ability to minimize soil disturbances, which helps preserve beneficial soil structure. These benefits are described further in Chapter 1, "Cropping Methods: Tillage & Residue Management". Increased soil organic matter can result in greater soil aggregation and soil porosity, which may increase water infiltration, reduce runoff, and reduce the risk of erosion. The stabilization and enhancement of soil organic matter also provides additional chemical, physical, and biological benefits from both crop productivity and erosion control perspectives. Other benefits include increased nutrient availability and utilization, enhanced resistance to pH change, and enhanced microbial diversity, aiding the suppression of disease and pests. In wet climates with slow-draining soil or low residue crops, filter strips, contour farming, or cover crops may be better suited for water quality protection. Cover crops can be planted to help control weeds and increase soil nutrients. Crop rotation is also used to control weeds, pests, and diseases while increasing soil fertility.

Resources for Planting Practices

The following practices involve planting trees, shrubs, crops, and grass. Each BMP involves methods to properly plant these species to ensure effective plant growth. See the NRCS planting guides for each BMP (these can be found on the NRCS website under Section 4 Conservation Practice Standards & Support Documents, after selecting Washington State in the Field Office Technical Guide). Local CDs can also help guide planting plans and methods.

BMPs for Soil Stabilization

Practices to Reduce Wind Erosion

Complex Multi-Row Windbreaks

Windbreaks, also known as shelterbelts, are linear or curvilinear, trees and/or shrubs in a single row or multiple rows (NRCS, 2022). Windbreaks have been shown to be most effective when planted as complex multi-row strips of large trees that are perpendicular to wind (see Figure 1). They can be established, enhanced, or renovated to accomplish a number of purposes on various land types except forest land. Windbreaks are especially beneficial as a BMP for water quality because of their ability to reduce wind-induced erosion, which reduces soil and pollutant contaminated surface water runoff. Windbreaks enhance plant health and productivity by protecting plants from wind damage, which in turn stabilizes soil. Windbreaks also manage snow distribution which may reduce ponding and flooding. Riparian buffers can act as windbreaks, but windbreaks may not provide the same overall functions and benefits as riparian buffers (see Chapter 12, Riparian Areas and Surface Protection, for buffer guidance).

Figure 10: A multi-row windbreak providing protection at the corner of an irrigated field (Whidbey Conservation District).

Table 2: Implementation Considerations for Multi-Row Strip Windbreaks

Category	Details
Lifespan	• Windbreaks have an indefinite lifespan as long as they are properly maintained and renovated as needed given tree survival/lifespan. • Renovations could take multiple years. • Plan for tree height maturity 20-years from establishment.

Land Area Requirements	• Consider geographical effects on tree growth.
	    ○ The East versus West side of Washington supports different species due to varying soil and climatic conditions. For example, conditions in the Colombia Plateau do not naturally support as much tree growth, and the area will have greater success with hedgerow plantings (see below) than windbreaks.
	• When choosing a windbreak location, keep in mind that windbreaks can protect an area ten times the tree height, and in some scenarios may provide some protection up to twenty times the tree height.
	    ○ NRCS Practice 386 recommends planting windbreaks at the edge of fields to provide additional protection (NRCS, 2016).
	    ○ Locate and design windbreak in locations with conditions that are ideal for successful tree growth and survival.

Category	Details
	○ Locate windbreaks in areas where wind speeds need to be slowed down to protect soils from destabilization. ○ When choosing a windbreak location, use a conservation plan map or photo to identify fields to protect from soil erosion, existing windbreaks, soil conditions, topography, prevailing wind direction, utilities, property lines, and roads. ○ Orient the windbreak as close to perpendicular (at a right angle) to the prevailing wind as possible. ○ Locate where snow deposits, snow melt runoff, and soil erosion will not cause safety hazards. • Follow cultural resource regulations when planting trees. • Consider planting windbreaks around roadside ditches or streams to prevent sediment runoff. ○ Windbreaks are not riparian buffers themselves but can be used alongside riparian buffer guidance (see Chapter 12, "Riparian Areas & Surface Water Protection") to prevent sediment from entering streams and provide benefits similar to riparian buffers.
Associated Costs[5]	Tree/Shrub Site Preparation (Conservation Practice 490) • Costs to prepare sites prior to establishing windbreaks range based on the site size and amount of undesirable vegetation to remove. • A 0.5-acre area with some undesirable vegetation could cost around $18.85/1000 square feet to prepare. • A six-acre area could cost up to $2,047/acre if it requires three treatments per year to remove undesirable vegetation. • A one-acre area requiring no chemical treatment and only hand-cutting vegetation can cost up to $2,331.55 per acre. Windbreak/shelterbelt establishment and renovation (U.S. Department of Agriculture, 2024 and 2025) • Windbreak/shelterbelt establishment and renovation can range based on the scenario. • Scenarios can cost between $0.43/foot and $9.99/foot for windbreaks with a typical size of 500 feet. For the least expensive scenario, costs include: ○ Truck equipment and power ($25.25/hour) ○ Hand tools and tree planting ($12.51/hour) ○ General labor ($33.98/hour) ○ Supervisor or manager ($55.32/hour) ○ Materials (Containerized or bare root conifer seedlings for $1.73/plant) • For more complex scenarios, additional costs can include:

[5] Cost estimates may vary by year and location. Costs displayed in this guidance were provided based on available data as of Spring 2025.

Category	Details
	○ Tractor (36.19/hour) ○ Small flatbed trailer ($10.32) ○ Equipment operators ($32.21/hour) ○ Medium potted shrubs ($14.34/each) ○ Medium potted conifer trees ($17.48 each) ○ Small bareroot shrub seedlings ($1.09 each) ○ Small hardwood tree seedlings ($0.90 each) ○ Large conifer tree seedling ($1.73 each) ○ 4 in x 18 in solid tube tree shelter ($1.82 each) ○ 4 in x 24 in. Solid tube tree shelter ($2.52 each) ○ 24' Mesh tree tube shelter (0.53 each) ○ Plastic cable ties ($0.07) ○ Wood stakes, ¾ in. X ¾ in. X 36 in. ($1.17) ○ Wood stakes, ¾ in. X ¾ in. X 48 in. ($2.09) • See Conservation Practice 650 for additional costs to implement windbreak/shelterbelt renovations. • Renovating windbreaks can cost between $3.87/foot to $6.84/foot, for windbreaks with a typical size of 500 feet. • Renovation costs account for: ○ Chainsaw ($6.28/hour) ○ Truck/pickup ($25.25/hour) ○ Pruning and hand tools ($2.31/hour) ○ General labor ($33.98/hour) ○ Specialist Labor ($133.49/hour) ○ Large shrub, bare root seedling ($4.01/each) ○ Tree seedlings range from $1.73 - $10.15 each depending on their species, size, and if they are potted, bare root, or containerized. A diverse range of options is planted, about 100 are planted for a 500 ft area. ○ Tree shelter, solid tube type 3-¼ in. x 24 in. Are $2.52 each and often 125 are needed fora 500 ft. Area. ○ If a dozer is needed to remove trees, the following are added on: ▪ Dozer, 140 HP ($99.84 /hour) ▪ Heavy equipment operators ($33.98/hour) ▪ Mobilization/large equipment ($919.30) • Several financial incentives can help with installing and renovating windbreaks: ○ The NRCS Environmental Quality Incentives Program provides technical and financial assistance, potentially including advanced payment, to address water and air quality, and reduce soil erosion. NRCS works with producers to develop a conservation plan. ○ The National Air Quality Incentive Program (NAQI) provides financial incentives for windbreaks as they create high air quality

Category	Details
	improvements with establishment, and medium improvement for renovations. ◦ Windbreak species can provide economic incentives for landowners who can plant crop trees and shrubs as part of the windbreaks.
Technical Requirements	<u>Materials</u> • Select native tree and/or shrub species adapted to soils, climate, and other site conditions. Do not use any invasive or noxious weed listed species. • Select plants that have the greatest potential for meeting landowner objectives to provide the desired level of wind protection in a reasonable timeframe (10 years). • Select species for the appropriate density and height for the site and consider conifers for year-round wind protection. • Select trees that can provide 25-50% windbreak density during snow-producing months. • When possible, select native species that benefit wildlife including pollinators and natural enemies of crop pests. • See the Cost section for a list of materials used to plant and manage windbreaks (e.g. plants, wood stakes, equipment, plant protectors). Materials vary depending on the windbreak design. <u>Design</u> • Follow NRCS 490 to prepare the site prior to plant establishment. • Follow NRCS 612 for establishing trees and/or shrubs. • Follow NRCS 441 Irrigation System, Microirrigation for supplemental water to ensure proper tree and/or shrub growth. <u>Height</u> • Protection from wind will be 10 times the tallest row of trees or shrubs 20 years from establishment, on the leeward side of a windbreak. • Adjust the height of the windbreak based on site productivity. • Adjust species and setback distances that allow for expected mature windbreak size to mitigate negative impacts of visibility, shading, and snow deposition. • The windbreak will reduce wind speeds by two to five times its height on the upwind side and up to 30 times on the downwind side, depending on the windbreak density. (Center for Agroforestry, 2021). <u>Length</u> • Length must be adequate to protect the site, allow for an “end effect” of turbulence, and accommodate changes in predominant wind direction at the end of windbreaks. • For maximum efficiency, the length of the windbreak should exceed the height by a 10:1 ratio (e.g., 300 feet tall should be 300 feet long). The

Category	Details
	length-height ratio reduces end-turbulence effects on the total protected area (Center for Agroforestry, 2021). <u>Width</u> • Width impacts density of the windbreak. Having more rows increases the density, value for wildlife, opportunities to produce tree products, and decreases wind. • Include three to eight rows of a mix of conifers and deciduous trees and shrubs (Center for Agroforestry, 2021). <u>Orientation</u> • Orient the windbreak as close as perpendicular to the predominant wind as possible. • USDA provides data on wind direction with the Wind Rose dataset[4]. • Use one or more "legs" (i.e. windbreak extensions oriented at right angles to the main wind break) where practical to provide protection from changing winds and increase the protected area (NRCS, 2022). <u>Density and spacing</u> • Density is impacted by plant species (e.g. deciduous vs. coniferous), distance between trees, and number of rows. Three levels of dense plant material can be created by combing low growing shrubs with medium and tall deciduous trees. Aim for 60-80% year-round density to maximize wind reduction. • Conifers are important to reduce wind year-round. • Space individual plants based on the growing area needed by each species. Plan to accommodate maintenance equipment. • Limit gaps in windbreaks which can become wind funnels that decrease windbreak effectiveness. • Windbreak density must be 50% during snow-producing months. <u>Species</u> • Place conifers on the windward side with deciduous species in the center. Place a row of shrubs on the interior (Center for Agroforestry, 2021). • Refer to local conservation districts for assistance with planting plans and to determine what species are best suited for the land, which will vary based on soil condition and climate factors. <u>General design considerations</u> • Prepare a proper implementation plan guided by NRCS 380 Windbreak Shelterbelt Establishment and Renovation. • Consult local conservation districts for guidance (see Table 4 for example guidance).

Category	Details
	• Do not plant trees or shrubs where they will interfere with above or belowground structures, utilities, irrigation, or moisture management systems or desired drains. • Prepare contingency plans in case of project challenges such as drought, weed invasion, or disease/insect impacts. • Prevent windbreak snowmelt drainage from flowing across a livestock area and prevent animal waste drainage from flowing into a windbreak. • Locate new rows of trees 50 feet from existing rows. • Consider where access roads are and prevent windbreak gaps that line up with prevailing winds as shown in Figure 12.

Operational and Maintenance Requirements	• Prepare an O&M plan, which ensures the practice will function as intended throughout its expected lifespan.
	• The plan will include ongoing activities that occur during use of the practice (operation), and repair and upkeep (maintenance). O&M activities include:
	    ○ Inspecting the planting at least annually and after major storm events or other disturbances.
	    ○ Maintaining protection for trees and/or shrubs during establishment (e.g., tube shelters, cages), and removing protective structures when plants are large enough to withstand environmental stressors.
	    ○ Providing supplemental water if needed during plant establishment.
	    ○ Treating woody debris by mulching or chipping to increase soil organic matter and decrease herbaceous weed competition.
	    ○ Removing and managing invasive and competing species.
	    ○ Thinning or pruning the windbreak to remove dead, injured, or diseased wood.
	    ○ Applying nutrients periodically to maintain plant vigor, following approved fertilizer recommendations.
	    ○ Protecting against adverse impacts including insects, diseases, competing vegetation, fire damage, spray drift, animals, etc.
	    ○ Monitoring tree or shrub establishment or renovation and replacing dead trees or shrubs as needed.
	    ○ Renovating a windbreak that has lost its functionality.
	    ○ Periodically removing some products from high value trees (e.g., medicinal herbs, fruit, nuts, etc.), provided the loss of vegetation or harvesting disturbance does not compromise the function of the windbreak.

Resources	• Contact your local NRCS office and/or CD to develop a planting plan for your site's windbreak. • Windbreak-Shelterbelt Establishment and Renovation (Code 380) • Tree/shrub site preparation (Code 490) for preparing the site prior to plant establishment. • Tree/Shrub Establishment (Code 612) when establishing trees and/or shrubs • Irrigation System, Microirrigation (Code 441) for supplemental water

Category	Details
	• Trees Against the Wind (Hanley and Kuhn, 2003) • Center for Agroforestry: Windbreaks • US Department of Agriculture Windbreak resources • Ophardt M. (2017). Mid-Columbia Community Forestry Council: *Windbreak Trees*, WSU Extension. • NRCS Cost Scenarios –Fiscal Year 2024 • NRCS Cost Scenarios – Fiscal Year 2025

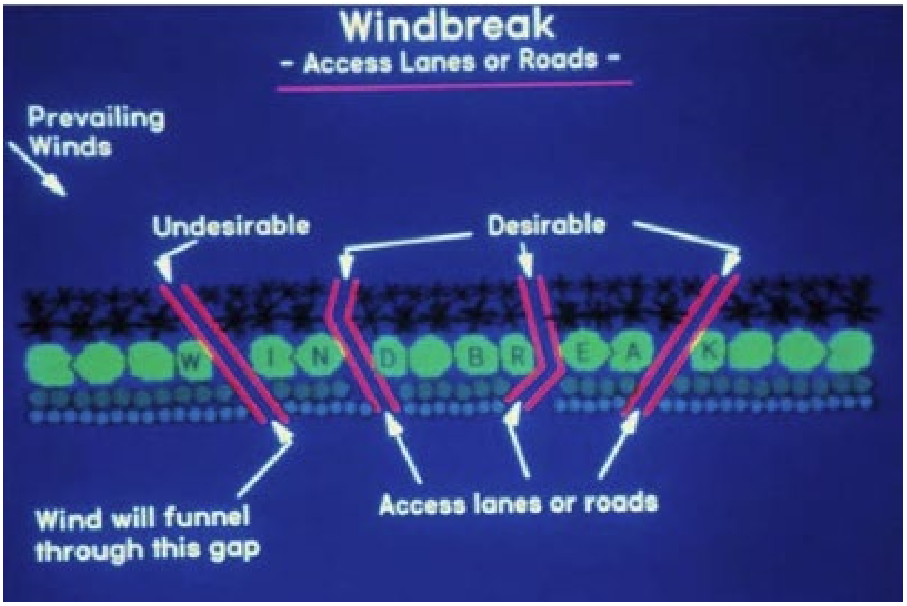

Figure 11: Examples of desirable and undesirable road placements though a windbreak (Center for Agroforestry, 2021).

Table 3: Traditional Design Planting Guide for Windbreaks (Hanley and Kuhn, 2003).

If you have room for a windbreak with only	Highest protection	Higher protection	Lower protection	Lowest protection
Four rows	Dense shrub Medium evergreen Tall evergreen Medium evergreen	Dense shrub Medium deciduous Tall evergreen Medium evergreen	Dense shrub Medium deciduous Tall deciduous Medium evergreen	Dense shrub Medium deciduous Tall deciduous Medium deciduous
Three rows	Dense shrub Tall evergreen Medium evergreen	Dense shrub Tall deciduous Medium evergreen	Dense shrub Medium deciduous Tall deciduous	Dense shrub Medium deciduous Medium evergreen
Two rows	Medium evergreen Tall evergreen	Dense shrub Tall evergreen	Dense shrub Tall deciduous	Dense shrub Medium deciduous
One row	Tall evergreen	Medium evergreen	Tall deciduous	Medium deciduous

Hedgerows

For areas that do not support large trees such as parts of the Columbia Plateau, hedgerows can help prevent wind erosion. Hedgerows resemble short narrow windbreaks with similar benefits but at a smaller scale. They are linearly established with dense vegetation in ditches and channels that are 15 feet wide and have been modified for agricultural uses (NRCS, 2008). Hedgerows can intercept airborne particulate matter and improve water quality and aquatic habitat. If properly designed, they can reduce wind speed over a distance 12 times the height of the hedgerow on the downward side and four times on the upward side of the hedgerow. In doing so, they minimize dust/soil erosion, and odors. They help control water flows and reduce topsoil loss from erosion (King Conservation District, n.d.).

Figure 12: Hedgerows Before and After, WSU Thurston County Extension.

Table 4: Implementation Considerations for Hedgerows.

Category	Details
Lifespan	• Hedgerows have an indefinite life span as long as they are properly maintained and renovated as needed based on plant survival and lifespan. • Hedgerow species have varying growth rates. • Plan for tree height to reach maturity 20-years from establishment. Renovations may require a number of years.
Land Area Requirements	• Hedgerow location considerations include: ○ Place in the best alignment and distance from crops to maximize protection against wind. ○ Protect hedgerows from livestock grazing and trampling to the extent necessary to ensure they will perform their intended purpose(s). ○ Consider proximity to irrigation sources, and site so that irrigation can be provided for the first two to three growing seasons. ○ Ensure that the hedgerow placement won’t impede equipment access. ○ Consider effects of hedgerow shade on crop productivity. ○ Consider hedgerow plants that spread via rhizome (underground stems), which may encroach on other plants and crop areas.

Category	Details

Associated Costs[6]	• Costs for hedgerow planting range from $10.01/foot to $16.64/foot, with a typical scenario size of 800 feet. Costs for the least expensive scenario can include:
	  ○ A pickup truck ($25.25/hour)
	  ○ Light tillage ($14.20/acre)
	  ○ Broadcast seed via ground operation ($13.96/acre)
	  ○ Hand and tree planting tools ($12.51)
	  ○ General labor ($33.98)
	  ○ Small potted shrubs ($7.79 each)
	  ○ 4 in x 36 in. Solid tube tree shelters ($3.90 each)
	  ○ 1in x 1 in x 36 in. Wood stake ($1.01 each)
	  ○ Low density native perennial grasses ($134.97/acre)
	  ○ Mobilization of small equipment when materials can't be transported by pick-up truck or with typical weights 3,500-14,000 pounds ($302.66 each)
	• For more expensive scenarios, other costs can include:
	  ○ Snow fence ($1.84/foot)
	  ○ Native perennial grasses, legumes, and/or forb mix for targeted wildlife/pollinator habitat or ecological restoration, with moderate commercial availability ($469.81/acre)
	  ○ Foregone Income, Wheat Dryland ($176.34/acre)
	• Other considerations include from the King Conservation District Hedgerows Handbook include:
	  ○ More plants are needed when planting them close to each other. However, the closer plants are planted the more they outcompete weedy species, which could reduce overall maintenance.
	  ○ Consider T-tape ($0.05) irrigation systems, versus emitter ($0.35/foot) irrigation systems. T-tape systems are less expensive but are more prone to damage, are not as effective, and irrigate a larger area which encourages more weed growth.
	• Financial Incentives include:
	  ○ The Environmental Quality Incentives Program (EQIP) provides technical and financial assistance, potentially including advanced payment, to address water and air quality, and reduce soil erosion. NRCS works 1:1 with producers to develop a conservation plan.
	  ○ The National Air Quality Incentive Program (NAQI) could provide financial incentives as hedgerows have proved to create air quality improvement.
	  ○ The Conservation Reserve Enhancement Program (CREP) provides financial and technical support to owners in planting native

[6] Cost estimates may vary by year and location. Costs displayed in this guidance were provided based on available data as of Spring 2025.

Category	Details
	vegetation as buffers along salmon-bearing streams. CREP covers the entire cost of project installation, includes a one-time signing bonus, and project maintenance is reimbursed for the first five years, and for fencing that excludes cattle from the buffer (NRCS, 2015). • Landowners can choose species with benefits such as flowers, fruit, and foliage. Fruit production can be an economic incentive. • The hedgerow establishment could be phased over time, breaking it into manageable sections based on budgets and needs. • Lastly, consider mulch costs. Arborists often provide free local mulch.

Technical Requirements	<u>Materials</u>
	• When choosing plants, think about plants that grow in a reasonable amount of time, have longevity and vigor, can be easily maintained, are resist against animal efforts, produce shoots close to the ground, are suited to the climate and soil type, can support resistance to disease, and are unattractive to livestock within the field.
	• Shrubs dominate hedgerows, reaching 10 feet in height.
	• Choose a main plant or two to constitute 60% to 70% of the hedgerow with a stable growth rate that will build the hedgerow's foundation and fill in gaps as the plants grow (Bentrup G, & Hoag, D, 2014).
	  ○ Consider using a mix of native evergreen and deciduous species and establish at least 2 native species that persist over winter (NRCS WA, 2008).
	  ○ Planting a variety of trees, hedges, and field margins (wildflowers, native grasses, grains, etc.) is most beneficial for wildlife.
	  ○ Use native woody plants, or perennial bunch grasses with erect stems that average at least three feet tall and persist over winter.
	  ○ Do not use any plant listed by WA as noxious weeds.
	<u>Design</u>
	• <u>Height and Length</u>
	  ○ Maintain a three foot minimum height. Hedges reach maturity at approximately 15 feet tall (NRCS, 2021).
	  ○ Consider the amount of shading the hedgerow will provide at maturity and its impacts on adjacent land growth.
	  ○ Ensure the hedgerow is long enough to protect the desired area from wind.
	• <u>Width</u>
	  ○ Maintain a minimum 15-foot width.
	  ○ The most common panting plan includes two rows.
	• <u>Orientation</u>
	  ○ Orient hedgerows perpendicular to the prevailing wind direction and upwind of odor producing or chemical application area.
	• <u>Density and spacing:</u>

Category	Details
	○ Use the Washington State Seeding Guide PM Technical Note 1 to determine plant densities. ○ The most common planting has offset rows with even distribution within rows. ○ When planting multiple rows, the downwind hedgerow should be no more than 12 feet from the upwind hedgerow (NRCS, 2024). ○ Different species have varying growth habits and spacing requirements. Plant shrubs 3-5 feet apart but plant trees 8-12 feet apart. A tighter hedge places some species as close as 8-12 inches apart depending on the species (King Conservation District, n.d.). ○ Space rows wide enough to accommodate mowing equipment. Rhizomatous plants are more challenging for maintenance because they spread between rows. A strategy is to allow taller shrubs and trees to grow for a year or two before filling in low-and-fast-growing plants (King Conservation District, n.d.). • <u>Species</u> ○ Understand site conditions including soil conditions and types, drainage capacity, and sunlight, to determine appropriate plants. Conditions in some WA areas, such as the Colombia Plateau, might not support growth of large trees to provide a full windbreak buffer, and so hedgerow species can be used as an alternative. ○ Contact your local CD to help develop planting plans. ○ Bare root and containerized seedlings accelerate hedgerow development. ○ The main species should have a good growth rate and be resilient to pruning. Add four-six addition shrubs or small trees to complement the main species, filling in gaps. ○ The inner row closer to livestock is best planted with species that can be trimmed and formed into a more solid barrier, and in which hedges are 8 to 12 inches apart. The outer row is best to plant a variety of species that can grow with a less formal shape that provides more wildlife habitat and is good for visual and noise barriers. ○ If along a stream or ditch bank, ensure to plant trees that have root mass to provide bank protection/stabilization. This will help reduce sediment runoff into ditches that may fill with and carry surface water runoff, or into streams that provide species habitat. For streams, also ensure trees can grow large and close enough to provide shade to keep water cool. Note that a hedgerow is not a riparian buffer, and riparian buffer guidelines (See Chapter 12) should be followed along streams. • <u>General design considerations</u> ○ Hedgerows may trap wind-blown sand or snow. ○ Use fencing to keep livestock from browsing hedge plants.

Category	Details
	○ Plant trees properly to ensure roots are well spread, starting level with the ground. Tamp soil, forming a slight depression. ○ Prepare sites in fall. Plant bare roots in early spring in Western WA. Planting with container stock is best done in fall or spring (King Conservation District, 2014). ○ Use herbicide as needed to reduce weed or grass competition.
Operational and Maintenance Requirements	• Landowners should develop a proper operation and maintenance plan and take the following into consideration: ○ Monitor plants every few weeks for the first growing season. The first few years require more frequent monitoring and maintenance until plants are established. ○ Supplemental plantings may be required when survival is too low to produce a continuous hedgerow. ○ Control competing vegetation until the hedgerow is established and after as necessary. ○ Use plant protectors to protect against browsing and trampling and protect vegetation from unwanted fire and livestock grazing. ○ Replace dead trees and shrubs every year in the spring or fall until the survival rate is near 100%. ○ Monitor and control pests. ○ Periodically apply nutrients as needed to maintain plant growth and strength. ○ A pre-emergent herbicide can be applied in the spring after the trees are planted and existing grass cover hasn't grown yet. Ensure herbicides do not come in contact with tree roots. ○ Monitor irrigation systems. Irrigation needs may differ depending on the environment. Plants typically require irrigation during the first two years of establishment. Some areas will only need additional watering during drought periods (Pierce Conservation District, n.d.). ○ Mow or mulch to prevent weed encroachment and encourage plant growth. Reapply mulch in the late summer, end of the winter, and after weeding (King Conservation District, 2014).
Resources	• NRCS 422 Hedgerow planting • King Conservation District Hedgerows Handbook ○ See page 9 for several WA case studies. • King CD Hedgerows ○ See for a list of suggested Hedgerow plants for western WA. • The Washington State Seeding Guide PM Technical Note 1 can be used to determine plant densities and should be clearly identified in the specification. • WA CD Hedgerows https://www.whatcomcd.org/hedgerow • Hedgerow Toolkit for Rural and Working Lands

Category	Details
	◦ This is an excellent handbook with details on the benefits of hedgerows, planning and implementing hedgerows, making a planting plan, and monitoring and maintenance. It includes a plant selection process and species guide, and templates for plant spacing and calculations. • Pierce CD Hedgerow Templates ◦ This provides a range of hedgerow planning templates in collaboration with local crop farmers. They cater to moist and dry environments. • Hedgerows and Windbreaks, Clallam Conservation District • Sortable Plant Table • Hedgerows for Rural & Working Lands in Western Washington • NRCS Cost Scenarios –Fiscal Year 2024 • NRCS Cost Scenarios – Fiscal Year 2025

No-Till

No-till is the practice of not turning over soil with tools. No-till limits soil disturbances to manage the amount, orientation, and distribution of crop and plant residue on the soil surface year around. One purpose of this practice is to reduce sheet, rill, and wind erosion, and excessive sediment in surface waters because it prevents soil de-stabilization and exposure. In this scenario, a windbreak that utilizes no-till provides roughness and soil stability and keeps the soil from being exposed. See Page 42 in Chapter 1, “Cropping Methods: Tillage & Residue Management” for additional information. Additional information can also be found in WA NRCS CPS 329 and NRCS Cost Scenarios for Fiscal Year 2024 and Fiscal Year 2025.

Conservation Cover

Conservation cover is the practice of establishing and maintaining permanent vegetative cover. Conservation cover provides a number of benefits, such as increasing soil health and wildlife habitat. Conservation cover supports soil stabilization and sediment capture by reducing sheet, rill, and wind erosion. Conservation cover also reduces sediment transport to surface water and reduces emission of particulate matter.

Conservation cover is similar to the crop cover practice (NRCS 340) but involves use of permanent perennial species rather than crop species to provide ground cover. Perennials are plants that do not need to be reseeded every year, requiring less plowing and herbicide applications. They are robust and protect soil from erosion. Ground/conservation cover is beneficial as it grows without requiring as much water as crops and provides stabilization between rows of crops. It is especially beneficial between rows in orchards and as strips on sloping lands.

Figure 13: An example of conservation cover. American Farmland Trust, 2025.

Table 5: Implementation Considerations for Conservation Cover.

Category	Details
Lifespan	• Conservation cover can persist as long as it is properly maintained.
Land Area Requirements	• Conservation cover can apply to most lands that need permanent vegetative cover, and to land where there is additional desire and need to stabilize soil and ensure sediment is captured and does not runoff into nearby waterways.
Associated Costs[7]	• Conservation cover cost scenarios range from $170.55/1000 square feet to $1,190.54/acre. • Costs for the least expensive scenario include: ○ Light tillage ($14.20/acre) ○ Mechanical weed control, vegetation termination ($26.95/acre) ○ No till/grass drill seeding operation ($21.25/acre) ○ Native perennial grasses, legumes, and/or forb mix for targeted wildlife/pollinator habitat or ecological restoration, with moderate commercial availability ($469.81/acre) • Costs mostly consist of mowing the conservation cover for maintenance after establishment. • Additional costs for more expensive scenarios can include: ○ Dry bulk fertilizer application by ground equipment ($7.58/acre) ○ Nitrogen supplied by Ammonium Nitrate ($0.73/pound) ○ Organic nitrogen ($0.28/pound) ○ Phosphorous - P205 supplied by Superphosphate ($1.02/pound) ○ Organic phosphorous ($0.09/pound) ○ Potassium – K20 supplied by Muriate of Potash ($0.80/pound)

[7] Cost estimates may vary by year and location. Costs displayed in this guidance were provided based on available data as of Spring 2025.

Category	Details
	○ Medium density native perennial grasses, legumes, and/or forbs ($153.79/acre) ○ Low density native perennial grasses ($134.97/acre) ○ Pickup truck ($25.25/hour) ○ Skilled labor ($52.76/hour) ○ General labor ($33.98/hour) ○ Primary tillage ($21.58/acre) ○ Chemical application performed by ground equipment (6.70/acre) ○ Glyphosate herbicide ($12.66/acre) ○ Irrigated wheat forgone income ($358.01/acre) ○ Dryland wheat forgone income ($176.34/acre) ○ Dryland oats forgone income ($178.30/acre) • Incentives include: ○ Many CDs have programs to rent out no till/grass drills. ○ Sustainable Farms and Fields is a grant program that supports farmers with projects that increase carbon sequestration and reduce greenhouse gas emissions. They provide financial assistance to help with eligible projects, equipment, seeds for cover crops, and other expenses.
Technical Requirements	Materials • Select a diverse mix of native herbaceous species adapted to soil, ecological sites, and climatic conditions, and that are aimed to reestablish diverse native plant communities. • Use native perennial plants that are not used for cropland agriculture or grazing. Species provide habitat for pollinators and other wildlife. Native grasses, legumes, and forbs can be selected based on conservation goals, resources and geographic region. • Use certified seed and planting stock adapted to the site when available. • If the rhizobium bacteria for selected legumes are not present in the soil, use appropriate inoculum to treat the seed. See NRCS Plant Materials Technical Note No. 5 (Title 190). • If the site has low-fertility soil, consider using slow-release nutrient sources instead of soluble fertilizer to improve the site without stimulating weeds. • Use natural mulches such as wood products or hay to conserve soil moisture, support soil life, and suppress competing vegetation. Design - Preparation • Contact your local CD or NRCS field office to provide ideas for plant species, planting rates, and planting methods best suited for the land. • Prepare the site by eliminating weeds that will prevent selected species establishment and growth and applying nutrients if needed. Mowing may be needed. • Ensure planting dates, seeding rates, planting methods, and seed handling and planting care are used to obtain and maintain conservation cover.

Category	Details
	• Comply with USDA Organic Regulation and NRCS resource page for Conservation for Organic Farmers for organic and transitioning-to-organic operations. • Make a plan that includes: all applicable purposes for the installation of the practice, field numbers and installation locations, recommended plant species, seeding rates and dates, seedbed preparation procedures, establishment methods, management actions to ensure an adequate establishment, and soil loss estimates and SCI results. • The Western Washington Pasture Calendar and the Inland Pacific Northwest Pasture Calendar are guides with extensive detail for grassland management. <u>Design - Establishment</u> • Day length, soil temperature, air temperature, water, nutrients, annual growth cycle, and management strongly affect plant growth. • The established stand will produce a positive soil conditioning index (SDCI) value. Use the SCI results available in current NRCS erosion prediction technology. • Determine and maintain the amount of plant biomass and cover needed to reduce wind and water erosion to the planned soil loss objective by using current NRCS erosion prediction technology. • Establish plants that can tolerate impacts of routine operations (e.g. orchard and vineyard alleys during mowing, spraying, or harvest operations) and provide sufficient ground cover in the planted area to minimize particulate matter. • If nitrogen fertilizer is used on sites where nitrogen-responsive weeds are present, delay Nitrogen application until the planted species are well established to avoid expected weed problems. • No-till or single tillage mitigates soil erosion in steep slope vineyards (Straffelini E. et al., 2022).
Operational and Maintenance Requirements	• Protect the cover from irreversible traffic and herbicide damage. • Periodically remove products such as high value trees, fruits, nuts, and herbs if removal does not compromise vegetation. • Revegetate bare spots. • Mow and mulch at minimum, at the beginning of the dry season. Continue to mow as needed during species establishment to reduce weed competition and control noxious weeds and invasive species after species establishment. • Mow and harvest using methods to minimize generation of particulate matter from perennial crops (such as orchards, vineyards, berries, and nursery stock).

Category	Details
Resources	• NRCS CPS 327 • Western Oregon and Washington Pasture Calendar • Inland Northwest Pasture Calendar • Washington State University: Herbaceous Perennials • NRCS Cost Scenarios –Fiscal Year 2024 • NRCS Cost Scenarios – Fiscal Year 2025

Cover Crops

Cover crops include grasses, legumes, and forbs planted for seasonal vegetative cover. Cover crops are similar in purpose and establishment to conservation cover but can provide additional uses for farmers and are more frequently used in Washington state. Cover crops can support the following:

- Reduce erosion from wind and water
- Maintain soil health
- Reduce water quality degradation by utilizing excessive soil nutrients
- Suppress excessive weed pressures
- Break pest cycles
- Improve soil moisture use efficiency
- Minimize soil compaction

Figure 14: Over-wintered, fall-planted annual cover crop plots at the Pullman PMC, Pavek, P., 2014.

Table 6: Implementation Considerations for Cover Crops.

Category	Details
Lifespan	• Cover crops are seasonal (spring annual or winter annual) but can be replanted and cover crop areas can persist as long as they are properly maintained and as long as the soil has proper nutrients for plant growth.
Land Area Requirements	• Cover crops apply to all lands requiring seasonal vegetative cover for natural resource protection or improvement.

Associated Costs[8]	• Cover crop costs range from $31.62/1000 square foot to $642.96/acre. Depending on the scenario, costs may include the following:
	
	Equipment installation
	• Chemical application performed by ground equipment ($6.70/acre)
	• No-till/grass drill for seeding ($21.25/acre)
	• Light tillage ($14.20/acre)
	• Mechanical weed control ($26.95/acre)
	• Pickup truck ($25.25/hour)
	• Walk-behind Rototiller ($33.98/hour)
	• Cultipacking ($10.14/acre)
	
	Labor
	• Skilled labor (52.76/hour)
	• General labor (33.98/hour)
	
	Materials
	• Glyphosate herbicide (12.66/acre)
	• Annual grasses ($40.79/acre)
	• A mix of annual grasses, legumes, and/or forbs ($61.36/acre)
	• Broadleaf herbicide for cropland and pasture ($10.10/acre)
	• Surfactant herbicide ($1.61/acre)
	• Certified organic annual grasses and legumes and/or forbs ($76.06/acre)
	• Cover crops can be planted in combination with companion cash/harvestable crops to provide economic incentives for farmers, as cover crops are not always profitable.
	• Incentive programs include:
	  ○ Environmental Quality Incentives Program (EQIP) Conservation Incentive Contracts offers annual incentive payments to implement management practices as well as conservation evaluation and monitoring activities.
	  ○ Conservation Stewardship Program (CSP) Re-enrollment Option
	  ○ Sustainable Farms and Fields Funding

[8] Cost estimates may vary by year and location. Costs displayed in this guidance were provided based on available data as of Spring 2025.

Category	Details
	▪ Piece Conservation Districts obtained funding from this program. Part of the funds were used to purchase materials for local distribution, allowing dozens of farmers to receive free crop seed (ArcGIS StoryMaps, n.d.). o Snohomish County's Cover Crop Seed Reimbursement Program provides financial assistance to farmers to plant a fall seeded cover crop. Producers can check with their local conservation district to see if they have an incentive program (Snohomish Conservation District, n.d.). o Skagit Conservation District's Cover Crop Grant Program.
Technical Requirements	Materials - Cover Crop Species • Cover crops include a mix of annual summer or winter legumes, grasses, crucifers, and/or other forbs. Select species compatible with other components of the cropping system. • Legume examples include hairy vetch, common vetch, crimson clover, Austrian winter pea, and fava bean. Legumes fix atmospheric nitrogen, adding the most plant-available N if terminated when about 30% of the crop is in bloom (Sustainable Agriculture Research and Education, n.d.). • Broadleaf crop examples include Phacelia and Brassica family. Broadleaf crops with tap roots penetrate soil layers, creating roots that are beneficial for soil stabilization. • Grain and other grass examples include cereal rye, winter wheat, oats, barley, and annual ryegrass. Fibrous grasses provide biomass and bind aggregates. • Ensure herbicides used are compatible with cover crop selections and purpose(s). Plant Characteristics • Select cover crops with characteristics to prevent erosion, effectively utilize nutrients, prevent weed growth, and not harbor disease. • When selecting species, consider soil type and conditions, season and weather conditions, cropping system, C:N ratio of the cover crop at termination, anticipated nitrogen needs of the subsequent crop, and nitrogen fixation by legumes. • Cover crops can grow with companion crops that are harvested as a cash crop (Sustainable Agricultural Research and Education, n.d.). • In one study (NRCS, n.d.): o Overwintering crops that produced the most biomass were cereals including winter triticale, winter barley, and winter wheat. These are not the best crops for diversifying rotations in the Pacific Northwest. o Non-cereal over-wintering crops that produced the most biomass from mid-September planting were forage turnip, "Nemat" arugula, "Kodiak" brown oriental mustard, hairy vetch, and several Austrian

Category	Details
	winter pea varieties, winter canola (when planted before September 1st). o Summer crops that produced the most biomass were warm-season species including sunflower, sorghum, sorghum-Sudan grass, proso millet, and safflower. • Legumes are best for adding nitrogen to the soil while grasses quickly establish cover to reduce erosion, compete with weeds, and capture nitrogen at the end of a growing season. Grasses and legumes are often used in combination for both benefits. • New seeding or planting of any perennial or annual legumes should be inoculated at the time of planting. See the Inland Pacific Northwest Pasture Calendar for more information on fertilization. Mixture selection • A mixture of plants maximizes the benefits of varying plant characteristics. If one species fails to grow, others will take its place. Include warm and cool season species to provide year-round cover (Sustainable Agricultural Research and Education, n.d.). • Select a mixture of two or more cover crop species from two different plant families so that the plants reach maturity to provide soil stabilization at different time periods that ensure ground is covered if one crop is harvested or replanted. Choose the cover crop to fit the harvesting time of the last crop (Snohomish Conservation District, n.d.). • If a cover crop is grazed or hayed, ensure crop selection complies with pesticide label rotational crop restrictions. Establishment Timing • Plant crop cover as early as possible prior to or after harvest. • Early planting dates (Aug-Sep.) optimizes biomass production of an over-wintering crop in E. WA dryland rotations. • Select species and planting dates that do not compete with the production crop yield or harvest. Cover crops may be established between production crops, companion-planted, or relay-planted into production crops. • Line up establishment timing with other practices to protect soil during critical erosion period(s) and when there are appropriate moisture levels. • Termination Timing • Meet current NRCS Cover Crop Termination Guidelines and the grower's objectives. • In areas with limited soil moisture, terminate cover crop growth early to conserve moisture for the subsequent crop. In areas of excess moisture, allow cover crops to grow as long as possible to maximize nutrient uptake,

Category	Details
	plant biomass production, soil stabilization, and prevention of rapid nutrient release. • Consider crop insurance criteria, time needed to prepare the field for planting the next crop, weather conditions, and effects of the cover crop on soil moisture and nutrient availability to the following crop. • Mowing certain grass cover crops (e.g., sorghum-Sudan grass, pearl millet) at six to eight inches high and prior to heading, thus allowing the cover crop to regrow can enhance rooting depth and density. • Legumes add the most plant-available N if terminated when about 30% of the crop is in bloom. • Turn the cover crop into the soil at the end of winter/beginning of spring so that the cover crop does not go to seed or flower, which could lead to the cover crop becoming a weed. • Utilize a winter cover crop after harvest in the fall to protect the soil. <u>Establishment Methods</u> • Prepare plans and specifications include field number and acres, species, seeding rates and dates, establishment procedure, timing, and forms of nutrient application if needed, dates and method to terminate the cover crop, and other information to establish and managing the cover crop. Planting should be consistent with applicable local criteria and soil/site conditions. • Ensure crops are planted year-round for sediment control (See Chapter 2 for more detail). Cropping Specifics can be found in the Cropping Systems Chapter. • Ensure cover crops are compatible with the landowner’s crop insurance when applicable. • For organic and transitioning to organic systems, comply with the National Organic Program (NOP) rules. • Maximize the combined canopy and surface residue cover to attain minimum 90-percent cover during periods of erosive wind or rainfall. • Use erosion prediction technology to determine the amount of surface and/or canopy cover needed from the cover crop to prevent erosion. • Turn soil and rake it smooth. Plant seeds one-fourth an inch deep but no more than two inches or they might not sprout. Note, the smaller the seed size the shallower it should be planted, larger seeds can be planted deeper and still attain successful stands. • Irrigate cover crops in late August or early September for better germination. • Compare costs and benefits of increased water uptake vs nitrogen fixing properties. Legumes use a lot more water which is more expensive, but they can reduce costs on fertilizer by introducing N into cover crops. • If using a cereal or grass/legume mix, seed the legumes two-thirds the rate than if the legume was the only crop. This lets the cereal crop establish in

Category	Details
	the fall/winter but not affect the legume's growth in the spring (Snohomish Conservation District, n.d.) • If the specific rhizobium bacteria for the selected legume are not present in the soil, treat the seed with the appropriate inoculum at the time of planting. • Both residue decomposition rates and soil fertility can affect nutrient availability following termination of cover crops. • Mulch areas with straw or compost if they are not harvested until November and December (Snohomish Conservation District, n.d.). • Tilling the cover crop if the soil is too wet can damage the soil structure. However, waiting too long can cause the cover crop to become woody and decompose more slowly. Mow or chop the cover crop if not tilling the soil. (Better Ground, n.d.). • Leave crop residues on the soil surface to provide mulching effects. Do not burn residue or harvest cover crops for seed (NRCS, 2025).
Operational and Maintenance Requirements	• Evaluate crop to determine if the cover crop is meeting planned purposes. If it is not, adjust management, change the species of the cover crop, or choose a different technology. • Protect against weed growth and grass suppression as discussed.
Resources	• WA NRCS CPS 340 • NRCS CPS 340 • NRCS Cost Scenarios –Fiscal Year 2024 • NRCS Cost Scenarios – Fiscal Year 2025 • Cover Crops for Home Gardens West of the Cascades (WSU Extension Fact Sheet) • Cover Cropping & Companion Cropping for the Inland Northwest • Evaluation of Cover Crops and Planting Dates for Dryland Rotations in Eastern Washington (NRCS Plant Materials Center) • Cover Crops in the Low-Rainfall, Wheat-Fallow Region of Eastern Washington • A significant amount of research is being conducted on cover crops. WSU Center for Sustaining Agriculture and Natural Resources lists a number of publications on Cover Crops (Washington State University, Center for Sustaining Agriculture and Natural Resources, n.d.). • Watch this video on cover cropping in the Puyallup Valley and see a story map of cover crop cases in Western Washington. • See Chapter 2 (Cropping Methods: Crop System) for more details.

Contour Farming

Terrace Filter Strips

Terraces are earthen embankments or a combination of ridge and channels that are constructed across the field slope. Terracing is helpful in reducing erosion and trapping sediment, managing runoff, and conserving soil moisture, as discussed in the Effectiveness section of this chapter. Terraces are effective when they are planted with permanent vegetation. However, terraces are not widely used or needed in WA due to climatic and land conditions. If terraced farming is implemented in WA, the practice will involve filter strips (NRCS CPS 393) and contour farming (NRCS CPS 330).

In-Field Contour Filter Strips

Contour filter strips are in-field filter strips along contours. Contour filter strips combine contour farming and filter strips. In-field contour filter strips reduce runoff, trap sediment, and promote water infiltration (see Chapter 2 Cropping Methods: Crop System for information on contour farming BMPs). In-field contour filter strips are intended to have permanent vegetation with no excavation and are designed for flatter areas compared to contour terrace farming. Filter Strips are covered extensively in Chapter 12, "Riparian Areas & Surface Water Protection", as an alternative practice in the inner or outer zones of a riparian buffer.

Chapter 9, “Runoff Control from Agricultural Facilities”, covers grassed waterways, vegetative treatment areas (VTAs), riparian areas, and filter strips, with the focus of diverting clean water from facilities. In some situations, water could have picked up contaminants and sediments that are important to infiltrate and capture. This section discusses how practices in Chapter 9 could also be used to capture sediment and treat contaminated water with infiltration.

BMPs For Sediment Capture

Grassed Waterways

Grassed waterways are shaped or graded channels with a broad and shallow cross section that are established with suitable vegetation to convey surface water at a nonerosive velocity to a stable outlet. Grassed waterways can serve as a conveyance for runoff during storm events. They can be combined with other dispersal or diversion methods. Grassed waterways require flatter land that is ideal for vegetative growth to allow for both controlled water transport and infiltration, and where equipment may need to cross the diversion. They trap sediment and pollutants in water runoff, providing a stable path for water runoff that does not become eroded or contribute to further sediment runoff.

Figure 15: Grassed Waterways (K. McKague, P. Eng. Ontario Ministry of Agriculture Food and Agribusiness)

Refer to Chapter 9, “Runoff Control from Agricultural Facilities”, for detailed implementation considerations for grassed waterways. Chapter 9 further describes implementation considerations for grassed waterways to treat runoff from agricultural facilities. Grassed waterways can prevent contaminated and sediment-filled water from running into waterways as the vegetation slows down water and traps nutrients and soil particles and increases infiltration. However, these waterways need to be maintained and mowed at the proper stubble height during the active growing season to keep plants actively growing and more leafy so sediment, etc. can be captured.

Grassed waterways can provide the following benefits:

- A non-erosive pathway for uncontaminated water to slow and infiltrate into the soil.
- A conveyance and infiltration method that is less disruptive to land (does not require deep ditches or pipes), allowing more efficient land use.
- Vegetation filters soil, nutrients, and pollutants from runoff and allows nutrients to remain in soil for continued vegetative growth.

This practice is extremely reliant upon successful vegetative growth. Establish vegetation as soon as possible and design with consideration of soil and climatic conditions. Plant close-growing crops nearby to construction of grassed waterway to help reduce flow. Select species that can achieve adequate density, height, and vigor within an appropriate time frame to stabilize the waterway. Follow NRCS CPS Code 342, Fransen et al. (2017), or Fransen et al. (2024). Grassed waterways will continue to be effective as long as they are properly maintained.

Filter Strips

A filter strip is an area of herbaceous vegetation that removes contaminants from overland flow. Filter strips reduce suspended soils and associated contaminants in runoff and excessive sediment in surface water, reduce dissolved contaminant loadings in runoff, and reduce suspended and associated contaminants in irrigation tailwater and excessive sediment in surface waters. Filter strips are established to protect sensitive areas from sediment, other suspended solids, and dissolved contaminants in runoff.

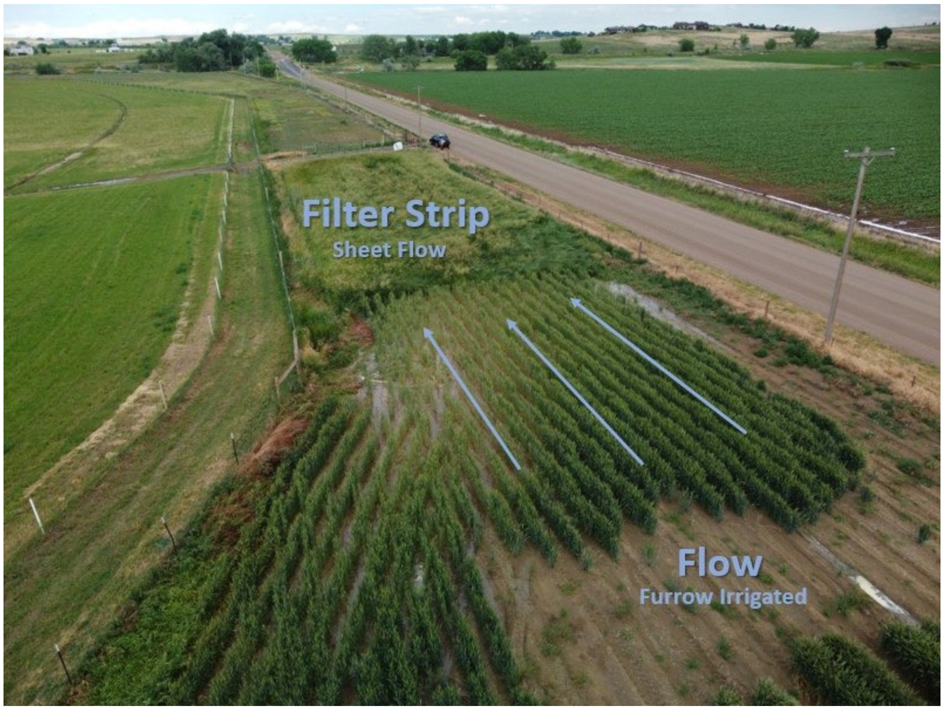

Figure 16: A filter strip designed to trap sediment, NC State University, 2023.

Table 7: Implementation Considerations for Filter Strips.

Category	Details
Lifespan	• A filter strip should be designed to have a 10-year life span. • Follow the procedure in Agronomy Technical Note No. 2, "Using Revised Universal Soil Loss Equation, Version 2 (RUSLE2) for the Design and Predicted Effectiveness of Vegetative Filter Strips (FVS) for Sediment." • The lifespan should be based on the amount of sediment delivery to the upper edge of the filter strip and ratio of "filter strip flow length" to "length of flow path" from the contributing area (NRCS, 2017).
Land Area Requirements	• Establish filter strips where areas need to be protected from sediment, suspended solids, and contaminants in runoff. • Locate filter strips immediately downslope from an area with a minimum 1% slope, where there is potential for sediment or contaminant runoff. • Land should be the proper length for water runoff, which is 20 minimum lengths for suspended solids and associated contaminants and 30 feet for dissolved contaminants and pathogen runoff.

Associated Costs[9]	• Filter strip scenarios can range in costs from $245.56/acre to $331.07/acre.
	• Costs scenarios can include:
	  ○ A pickup truck ($25.25/hour)
	  ○ Light tillage ($14.20/acre)

[9] Cost estimates may vary by year and location. Costs displayed in this guidance were provided based on available data as of Spring 2025.

<table>
<tr><th>Category</th><th>Details</th></tr>
<tr><td></td><td>

No Till or grass drill for seeding ($21.25/acre)
Perennial grasses, legumes, and/or forbs of low density ($47.76/acre)
Native perennial grasses of medium density ($192.81/acre)
Perennial grasses, legumes, and/or forbs of high density ($88.70)
All terrain ATV vehicles ($18.05/hour)
Dry bulk fertilizer application by ground equipment ($7.58/acre)
Nitrogen supplied by Urea ($0.77/pound)
Phosphorous supplied by Superphosphate ($1.02/pound)

Filter strips take land out of production, which can be an economic cost to producers depending on potential income from crop production.

</td></tr>
<tr><td>Technical Requirements</td><td>

Follow guidance on filter strips on pages 29b and 35b in Chapter 12.
Use in conjunction with tillage practices recommended in Chapter 1 (Cropping Methods: Tillage & Residue Management).
The maximum gradient along the leading edge of filter strip will not exceed one-half of the up-and-down-hill slope percent, immediately upslope from the filter strip, up to a maximum of five percent. Filters strips with the leading edge on a contour will function better than those with a gradient along the leading edge.

<u>Vegetation</u>

The filter strip will be established to permanent herbaceous vegetation.
Select species that will:

Withstand partial burial from sediment deposition.
Tolerate herbicides in any runoff to the filter strip.
Produce stiff and high density stems near the ground surface.
Grow in site conditions and for their intended uses.
Quickly achieve adequate density and vigor to stabilize the site
Sufficiently to permit suited uses with ordinary management activities

<u>Establishment</u>

Perform site preparation and seeding/planting at a time and in a manner that best ensures survival and growth of selected species.
Establish filter strips prior to the irrigation season so that the vegetation is mature enough to filter sediment.
Seed when soil moisture is adequate for germination and establishment and when tillage for adjacent crop does not damage the seeded filter strip.
Use small grain or other suitable annual plant species for vegetation.
Ensure that stem density is great enough to trap soil and that plant spacing is no greater than 4 inches (about 16–18 plants per square foot). Higher seed density is more effective. Use erosion technology to determine trapping efficiency.
Increasing the width of the filter strip beyond the minimum required will increase the potential for capturing more contaminants in runoff.

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Category	Details
	• Filter strip width (flow length) can be increased as necessary to accommodate harvest and maintenance equipment. • Control any invasive plant species through mowing, herbicides, and hand weeding prior to establishment.
Operational and Maintenance Requirements	• Vegetation should remain taller on the borders and perimeters of fields compared to in-field. The additional organic matter will help capture surface water and sediment runoff. • Harvest above ground filter strip biomass at least once per year when needing to remove phosphorous and excessive contaminants that have built up in plant tissue. This can help encourage continued dense growth. If nutrient levels are too low to maintain the desired species composition and stand density, apply supplemental nutrients. • If Prescribed Burning (CPS Code 338) is used to manage and maintain the filter strip, develop an approved burn plan. • Continue to control undesired noxious weed species. • Inspect the filter strips after storm events. Repair any gullies and remove unevenly deposited sediment accumulation that will disrupt sheet flow. Reseed disturbed areas and take measures to ensure flow is distributed evenly through the filter strip as best as possible. • Periodically regrade filter strips and reestablish the filter strip vegetation in regraded areas, if needed. • If grazing is used to harvest vegetation from the filter strip, the grazing plan must ensure that the integrity and function of the filter strip is not adversely affected.
Resources	• Pages 29b and 35b in Chapter 12. • Revised Universal Soil Loss Equation Version 2 (RULE2) • NRCS CPS 393 Washington: Filter Strips • NRCS CPS 393: Filter Strips • NRCS CPS 338: Prescribed Burning • NRCS Cost Scenarios – Fiscal Year 2024 • NRCS Cost Scenarios – Fiscal Year 2025

Vegetative Treatment Areas

VTAs are areas of permanent vegetation used for agricultural wastewater treatment. VTAs should be used in conjunction with other BMPs to manage runoff downslope of diversion methods (e.g., ditch diversion, grassed waterway, underground outlet, or subsurface drain) on large areas of flat land in which soil conditions allow water infiltration and vegetative growth. Past research has shown that contaminants contained by feedlot runoff are too concentrated to be discharged into surface water, even after being treated by a VTA.

Figure 17: VTAs require larger areas of flat land covered in vegetation to infiltrate water. Diversion methods such as underground outlets can outlet water (Wayne County Soil & Water Conservation District).

Refer to Chapter 9, "Runoff Control from Agricultural Facilities", for detailed implementation considerations for VTAs. Chapter 9 describes VTAs in detail with a focus on clean water runoff from agricultural facilities. VTAs can prevent contaminated and sediment-filled water from running into waterways as the vegetation traps and infiltrates water, reduces nutrients, pathogens, and other contaminants.

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