Introduction

This practice guide contains information for planning and applying seasonal vegetative cover according to NRCS Pennsylvania's Conservation Practice Standard Cover Crop (340). Use this guide to develop implementation requirements to apply the practice in the planned location.

Cover Crops do not only apply to field crops since orchard, vineyard, or vegetable operations may also use seasonal covers in between rows. Establishment of permanent vegetative cover should follow the criteria of the appropriate vegetative standard for conservation cover or critical area planting.

References used to develop this guide are listed at the end of the document. The following documents are the primary sources of the characteristics of cover crop species identified in this guide. Review the sources directly for further details needed to meet client objectives and socio-economic considerations.

1. Penn State Agronomy Guide, current edition
2. Penn State Organic Production Guide, current edition
3. Penn State Extension Fact Sheets
4. Managing Cover Crops Profitably, 3rd edition, 2007
5. Cornell Cover Crops for Vegetable Growers website
6. USDA ARS Cover Crop Chart, current version
7. USDA NRCS Plants Database website

Selecting Plant Species

Before selecting cover crop species, the existing conditions of the natural resources affected by growing crops in the field need to be understood. Proper selection of cover crop species and practice purposes address both the needed resource improvements and farming objectives.

The following tools and methods are used to evaluate existing resource conditions and assess the effects of applying cover crops to support one or more purpose(s). To assess the effects of cover crops on reducing erosion, use the latest version of the Revised Universal Soil Loss Equation (RUSLE). Improving soil health is assessed using a combination of in field observations and lab tests for the physical, chemical and biological properties of the soil. The Soil Condition Index is used to document organic matter increases. Penetrometers are used to find compacted soil layers. Chemical tests and proper interpretation procedures approved by Penn State University are used to assess the presence of excess nutrients. Soil moisture can be estimated by feel and appearance. Weed pressure and pest cycles are assessed by observation.

To select cover crop species that best support the identified purpose(s) of the practice, start by reviewing the ratings in Table 1. Tables are attached at the end of this guide. Natural resource improvements expected from applying the practice according to the criteria of each practice purpose are described in the Cover Crop Practice (340) Overview Fact Sheet.

Once cover crop species addressing the planned purpose(s) are identified, compare the strengths and weaknesses of their characteristics listed in Table 2 to ensure that they are compatible with the climate and planned cropping system for the area.

Fitting cover crops into a crop rotation requires additional knowledge about the preceding crop, the cover, and the next crop planned in the rotation sequence. USDA ARS's Cover Crop Chart presents a table of cover crops arranged by leaf type – broadleaves and grasses - and predominant growth periods of cool or warm season. Broadleaves are split into legumes and other broadleaves. Growth cycle, plant architecture, water use, C: N ratios, crop residue effects, and other characteristics described are helpful in determining which cover crop best fits in between the sequence of production crops.

Another important consideration in planning an optimum sequence of cover crops and production crops is cover crop effects on arbuscular mycorrhizal fungi. Most agricultural crops form symbiotic associations with arbuscular mycorrhizal fungi (see Table 2) that allow plants to provide sugars to the fungi in exchange for soil minerals and water it could not otherwise access. Two important families that do not form such symbiotic relationships are Brassica (also informally known as Crucifereae which include mustards, radishes, cabbage, rapeseed, and canola) and Chenopodiaceae (beets and spinach). Mycorrhizal fungi are ubiquitously distributed in normal biologically active soils. Tillage, long periods of soil bareness, and non-host plant species disrupt their effectiveness. Adding host cover crop species provides a continuity of habitat for this important soil microbe.

No guidance is provided in Table 1 for which cover crops to select for use as forages for hay or grazing purposes. Grazing cover crops has been documented to provide additional soil health improvements and significant savings in feeding costs. Consult a grazing specialist for guidance to graze cover crops or harvest them as hay or silage.

Finally, when selecting cover crop species, consider multiplying and diversifying their positive effects by establishing a mix of complementary species.

Developing Cover Crop Mixes

When considering establishment of a cover crop mixture, sometimes informally referred to as "cocktails", selecting complementary species requires additional guidance beyond the scope of this practice guide. Rates for an individual species in a mix are often much lower than when seeded as the sole species of a pure stand. Considerations may include plant structure, seed size, row configuration, nitrogen acquisition strategies, and others. For guidance on developing cover crop mixtures, refer to eXtension's publication *Making the Most of Mixtures: Considerations for Winter Cover Crops in Temperate Climates* located in the practice folder in Section IV of the FOTG.

Cover crop mixtures may be planted at custom recommended seeding rates specified by seed companies, if: (1) rates are published for typical growing conditions in the seeding area, and (2) all species are planted at the proper time. Since many species used as cover crops are also

used for forage or grain production, be careful to use rates needed to meet the purpose(s) of the cover crop. A sample of published cover crop mixes is presented in Table 4.

Determining Actual Seeding Rates

Recommended seeding rates for establishing an adequate final plant stand using a no-till drill are found in Table 2 in pounds per acre.

To determine actual seeding rates, the recommended seeding rates listed in Table 2 may need to be adjusted in consideration of several factors: seeding a single species or a mixture, seeding methods other than a no-till drill, seed quality and expected plant mortality rates.

The recommended seeding rates listed in Table 2 are for a single species seeding (pure stand). When a mix of species is planned, the recommended seeding rate of each individual species must be adjusted to reflect only its own specific percent of the total mixture. Each individual seeding rate must be then added to determine the 100% total of the recommended seed mix seeding rate.

Recommended seeding rates must also be adjusted for other methods of seeding being used. If broadcast seeding and culti-packing in average seedbed conditions, increase the seeding rate by 25-50% to account for lower probability of proper depth and spacing conditions. If aerial seeding, increase the seeding rate by 50%.

Finally, seed quality and growing conditions at seeding time need to be considered. The final plant stand density will be less than the seeding rate due to mortality. Having the proper plant density is important because it is essential to meeting the purpose of the seeding and the vigor of the cover crop. Excessively high plant densities cause plants to compete for available food and water, whereas extremely low plant densities may provide the opportunity for weed invasion. Higher plant densities are good for situations where quick cover and protection is desired while a lower plant density of individual species may be used within a mix to allow space for complementary companion species.

To assure a successful final plant stand establishment of a specific plant population density, an adequate amount of quality seed must be planted. All seed shall meet the current requirements of Pennsylvania Department of Agriculture's regulatory Seed Program of the (Pennsylvania Seed Act 164) as applicable. Seed purchased from a commercial supplier shall be fully labeled. Check the seed tag or have farm grown seed tested for expected germination and purity rates. Purchased seed or testing of farm grown seed may be required for financial assistance programs.

The percent germination rate and percent purity of seed of each seed lot is used to calculate the percent pure live seed (% PLS). The actual seeding rate needed to plant and determine purchase quantities (or produce on the farm and test) is then calculated by dividing the recommended seeding rate by the percent PLS of the actual seed lot being used.

Example of calculating actual seeding rate

For broadcast seeding Red Clover

From Table 2, the recommended seeding rate is 10 lbs. per acre.

Adjust recommended seeding rate for broadcast method by increasing it 50%. Calculate: 10 lbs. + 50% of 10 = 15 lbs. adjusted recommended seeding rate.

From Seed Tag for a bag of Red Clover: Germination 85%, Purity 95%

Calculate Seed Quality: 85% Germination X 95% Purity = 80% Pure Live Seed (PLS)

Adjust again for Seed Quality: Calculate: 15lbs adjusted seeding rate/80% PLS = 19 lbs

Final Answer: To assure an adequate final plant stand of Red Clover, broadcast an actual seeding of 19 lbs. from a seed lot with 80% PLS quality in order to achieve the same expectations from drilling 10lbs. of red clover from a seed lot containing 100% PLS.

To evaluate if the seeding rate is being achieved, check how many seeds of each species are distributed per square foot. Each plant species has different growth habits and characteristics so it is import to assure the right density of each is obtained for meeting the planned purpose(s) or management objectives. Using the # of seeds per lb. from Table 5 (species specific data provided by USDA Plant Materials Program), convert the recommended seeding rates in lbs. per acre listed in Table 2 to seeds per square foot.

For example, 250,602 seeds per lb. of Red Clover X the 10 lbs. per acre recommended seeding rate = 2,506,020 seeds per acre, divided by 43,560 SF per acre shows you need 58 seeds per SF. Similarly, calculations for Austrian Winter Pea show that one would only need 5 seeds per square foot. Note that Table 5 shows how different varieties and even lots of a variety vary in the number of seeds in one pound.

Determining Seeding Date Range

Determine cover crop seeding dates by identifying the optimum season seeding reliability date range. Make sure to check when planning a winter cover crop if the species is hardy for the planning area. Identify the USDA Plant Hardiness Zone (PHZ) listed in Table 2 for the crop species and check if the extent of the PHZ shown in Figure 2, a map of USDA Plant Hardiness Zones in Pennsylvania, occurs in the planning area.

Find the optimum season seeding reliability for a cover crop species in Table 2. Then use Table 3 to convert the optimum season to a date range for the Cover Crop Zone where the practice is planned. A map of Cover Crop Zones which closely align with Major Land Resource Areas (MLRA) boundaries adjusted to county borders is found in Figure 1 just above Table 3. Farmers

will then use the date range to determine the actual seeding dates by adjusting for moisture and growing conditions actually occurring that year.

Also make sure that the seeding date range meets the planned purpose(s) of the practice. If a farm is located in a colder/lower PHZ within a Cover Crop Zone, consider seeding winter covers earlier in the optimum seeding season. Table 2 shows the latest fall seeding date for erosion control purposes. Seeding earlier is recommended to allow more pre-winter growth. In areas with soils having high N leaching potential, risk of P loss, or compaction consider seeding cover crops at least 1-2 weeks earlier. When winter erosion control is not a concern, the latest fall seeding date may be extended an additional 5 days in all zones if the desired spring biomass can be achieved prior to cover crop termination.

Seeding Cover Crops

Inoculating Legume Seed

Legumes will fix nitrogen if the specific rhizobium bacteria are present in the soil or if seed is inoculated at the time of seeding. Evaluate cropping history to determine if the appropriate bacteria are present. No suitable lab tests exist at this time. If present, nodules will be pink. To avoid failure, inoculating every seeding is recommended. The bacteria strain for inoculating legume seeds shall be a pure culture specific for the legume species:

Legume Species:	Bacteria Strain**:**
Clovers (Red, Alsike, White, Berseem, Crimson)	*Rhizobium leguminosarum* biovar *trifolii*
Subterranean Clover	*Rhizobium leguminosarum* biovar *trifolii*
Hairy Vetch, Field Pea	*Rhizobium leguminosarum* biovar *viceae*
Sweet clover, Alfalfa	*Sinorhizobium meliloti*
Soybean	*Bradyrhizobium japonicum*
Cowpea, Sunn Hemp	*Bradyrhizobium sp. [Vigna]*

Fertilization

Cover crops may not require additional fertilization. Fertilization may be necessary if the goal is to 1) produce high biomass to build soil organic matter with a cover crop like sorghum-sudangrass, or 2) produce a large root to reduce soil compaction with a crop like forage radish. Apply additional lime, fertilizer and other organic by-products using rates, form, timing and placement method consistent with a current soil test report and Penn State Extension recommendations.

Preparing the Site (Seedbed Condition & Weed Control)

Prepare the site to ensure successful establishment of the cover crop. Site preparation considerations include seedbed preparation needs and weed pressure.

Seedbed preparation is usually not needed when using a no-till drill or planter, and is generally not possible when over-seeding or interseeding into a standing production crop. When using no-till drills or planters, preceding crop residues should be spread evenly before seeding a cover crop.

When seeding a cover crop following harvest of a production crop and using a conventional seed drill or broadcasting methods, prepare a seedbed by chiseling and/or disking.

Existing annual weeds should be controlled if sufficient pressure exists to hinder establishment of the cover crop. Perennial weeds may require specific control strategies. If spraying, refer the client to a consultant or Penn State Extension Educator to determine proper herbicide recommendations. Advise clients to follow manufacturers' label rates and guidance when using herbicides. Herbicide residue carryover from previous crop may cause cover crop establishment problems**.** For additional guidance, see reference *Improving the Success of Interseeding Cover Crops in Corn* on Penn State Extension's Crop and Soils Cover Crop webpage.

Selecting Seeding Equipment and Methods

Generally speaking, cover crop seeds are small and more suited to seeding with a drill or broadcast seeder, rather than a corn planter. There are many types of drills and broadcast seeding equipment. If suitable equipment doesn't exist on the farm, consider advising use of a custom operator to get started. The most important consideration in selecting seeding equipment and methods is obtaining good seed to soil contact, essential for successful germination. Optimum seeding conditions that result in good seed to soil contact include:

- Seeding on moist, friable, weed-free soil immediately prior to residue additions from harvest, applications of organic matter including manure, or immediately prior to soybean leaf drop;
- Seeding on friable, weed-free soil when adequate soil moisture is present or precipitation imminent;
- Seeding during freeze-thaw cycles with appropriate species also known as late fall dormant and late winter frost seeding.

Seeding depth is also important consideration to obtain the best germination. It is generally related to seed size however moisture and light are also factors. Larger seeds are planted deeper. Avoid seeding small seeds too deep and large seed too shallow. Plant deeper in lighter sandy soil, and less deep in heavier clayey soil. Seeding depths can be found in Table 2 as well as the USDA ARS Cover Crop Chart.

Using drills improves seed to soil contact over broadcast methods. While conventional drills may be used, no-till drills and not-till methods are highly recommended to minimize soil disturbance and reduce erosion, conserve plant available water, and improve soil health.

A new and specialized type of seed drill known as an interseeder is used to sow a cover crop into a standing row crop. Interseeding cover crops in corn is a promising management that

could improve the adoption of cover crops where they have not been feasible before. Penn State Extension generally recommends interseeding using specialized no-till drills at the V5 to V7 growth stage of corn. Follow guidance found in Penn State Extension publications, such as *Improving the Success of Interseeding Cover Crops in Corn* and others, when planning this method of establishment. Interseeding cover crops into taller corn is an alternative utilizing highboy-type equipment at the V10 – V11 growth stage.

The small size of cover crop seed also works with another new type of seeder on the market known as an air seeder. Air seeders use short disc harrows to roughen the surface and propels seed at a high velocity down vertical tubes onto the soil surface. They can be considered minimum-tillage. At this time, air seeders are typically used on larger operations needing to cover a large area fast but due to their size are not used in small fields.

Broadcast seeders are considered the most economical way to disburse seed to large areas of land; however, it is critical to assure good seed to soil contact to obtain acceptable germination rates. Traditional broadcast seeding is defined as sowing seeds across an area by scattering either by mechanical means or by hand. The timing of broadcast seeding is key to good seed to soil contact and successful germination. Most cover crops will not germinate well when broadcast on a compacted or crusted soil surface. When broadcasting, a culti-packer may be used to improve seed to soil contact. Broadcasting cover crops into standing crops, referred to as over-seeding, can be successful when seed to soil contact can be obtained.

Mechanical broadcast seeders typically are cyclone spreaders driven by a tractor power-take-off (PTO), an electric motor, or by hand operation. Hopper type fertilizer spreaders may also be used. Aerial broadcast (using an airplane or helicopter) seeders may be used to cover large inaccessible areas, however risks of poor seed to soil contact are high. Finally, many small areas are not adapted to mechanical seeding and are instead sown by using small hand spinners or even scattering by hand.

Dormant seeding involves broadcasting appropriate seed in late fall or early winter just after the ground has frozen and the temperature is low enough to prevent germination. Ideally this is just prior to snowfall. Seeds remain dormant under the snow through the winter and emerge in spring. Seeding after the late date for erosion control may result in successful spring growth depending on weather conditions affecting newly germinated plants.

Frost seeding involves broadcasting appropriate seed just after snowmelt in late winter/early spring. The subsequent freeze-thaw cycles act to work seed into the soil. Frost seeding should be done early in the morning while frost is still in the soil. Seed early enough to allow for several freeze-thaw cycles.

Neither dormant, frost, nor aerial seeding methods are completely reliable but may be considered for certain purpose(s) when a cover crop cannot be established in the fall due to late harvest of the production crop. Never plow, cultivate, or operate heavy equipment on wet/ thawed soils. Broadcasting on snow is not recommended because the seed will wash away.

Assessing Cover Crop Plant Stands

Follow Penn State Extension guidance for assessing cover crop stands (plant population density counts) to determine if objectives have been achieved. For the Red Clover cover crop example, Agronomy Facts 67: Management of Red Clover as a Cover Crop states that for nitrogen fixation, a 100 percent plant stand is five to six plants per square foot after at least one year of growth.

Terminating Cover Crops

Cover crop species may winter-kill or over-winter. Species that winter-kill are killed by frost while over-wintering species must be terminated before they compete with the production crop. Cover crop termination methods include mechanical cutting, rolling and crimping, tillage, grazing, or herbicide application.

Termination of the cover crop 2 to 3 weeks ahead of production crop planting is typically done to cause the cover crop to desiccate and its residue to turn brittle dry. This is especially helpful to prevent hairpinning during no till planting. Hairpinning is when fresh residue becomes trapped in the crop seed furrow and interferes with good seed to soil contact necessary for good germination rates. Early termination may also prevent soil moisture depletion, nitrogen immobilization, allelopathy and undesired reseeding. Timing of cover crop termination and managing cover crop surface residue must meet the criteria for the purpose(s) of the cover crop. Planting a production crop directly into a living cover crop, a new management practice called planting green, is currently being researched.

For most cropping systems, it is not desirable to allow the cover crop to produce seed due to risk of future weed pressure. Harvest of seed or grain is not permitted by the cover crop standard as it is incompatible with crop insurance rules. If the client's objectives include harvest for seed or grain, plan management of the crop as a production crop according to the applicable criteria in the conservation standard for crop rotation. When harvesting as a forage for hay or grazing is planned, recommend applicable criteria in the forage harvest management or prescribed grazing standards. When enrolled in applicable USDA programs including crop insurance, ensure cover crops are managed to be compatible with NRCS Cover Crop Termination Guidelines.

Winter-Kill Cover Crops

Selection of species that are killed by frost or other extreme winter weather conditions is an advantage when there is a need to plant production crops early in the spring. While these crops may scavenge nutrients in the fall, they tend to produce less residue and less nitrogen if a legume than an over-wintering species. Species that winter-kill include oats, peas, radish, and sunnhemp. Especially tough winter conditions may terminate species that in normal years over-winter so pay attention to proper fall management of over-wintering cover crops.

Mechanical harvest or mowing

Most annual plants may be terminated by mechanical cutting once the cover crop has reached a reproductive growth stage. Terminating earlier during the vegetative growth stage risks regrowth. *Note: harvesting a cover crop for forage removes some of the nutrients.*

Roller/Crimping and Planting Green

Cover crop roller/crimpers can also be effective for terminating annual cereal grains. A roller/crimper has blunt blades or knives arranged on the cylinder that crimp or crush the stems of the living cover crop, which then kills it. Rollers flatten and crimp susceptible cover crops leaving an intact mat of soil protective mulch. Orienting the rolling of the residue uniformly in the same direction as planned to plant the production crop facilitates the planting operation, crop emergence, and weed suppression.

In general, for success in this termination method, wait until cover crop reaches full reproductive stages. A cereal grain generally needs to be well into flowering in order for the roller/crimper to provide acceptable control alone. Consistent hairy vetch control may be achieved when small pods are visible (early pod set) on the upper nodes of the plant counting down from the top. A number of cover crops are not controlled by the roller/crimper alone including biennial or perennial legumes (alfalfa, red clover, etc.), canola, and annual ryegrass to name just a few.

A new technique referred to as “planting green” where the cover crop roller/crimping operation is conducted at the same time (instead of 2 weeks ahead) as the production crop is planted is still under research at this time. Roller/crimpers are added to planters to allow for one pass across the field and limit crop planting issues.

Tillage

Terminating cover crops by tillage is generally not recommended as tillage offsets the improvements in soil structure provided by the cover crop and no till planting. In vegetable operations or organic small grains, tillage may be considered to incorporate cover crop residue to accelerate their break down and prepare a suitable production crop seed bed. Limited tillage may also help control perennial weeds when herbicides are not acceptable. Any planned tillage operation should be carefully evaluated and include mitigation strategies to address its adverse effects.

Grazing

Grazing has the potential for effective cover crop termination but results may vary with cover crop species. While grazing in some cases can terminate a cover crop, generally speaking there is no definitive way to assure growth has ended, which will vary based on weather, soil and the type of cover crop grown. Consult a grazing specialist for guidance with this method.

Herbicides

Most cover crops are fairly easy to control in a “burndown” herbicide program. If the cover crop is to be terminated with herbicides, assure that timing and selection of herbicides achieves a complete kill. Translocated herbicides will perform better during active plant growth

conditions. A daytime temperature above 55^{o} and night time temperature above 45^{o} is needed for good translocation. During cool weather periods, application should be made during the warming part of the day (i.e. 9 AM to 3 PM) to allow time for the plant to translocate the herbicide. Follow all federal, state, and local guidelines and the manufacturer's label when applying herbicides. For additional considerations on using herbicides to control cover crops, contact a consultant or Penn State Extension.

Economics

Cover crops can improve a farm's bottom line in many ways, by reducing fertilizer needs, lowering weed and pest pressure, improving yields and more. Careful planning and selection may achieve both immediate savings and long term risk reductions.

Evaluating Cover Crop Practice Applications

New cover crop management and establishment techniques continue to emerge from university and private research, on and off the farm. To evaluate how well cover crops are meeting planned purpose(s) under changing conditions, consider conducting comparison field trials. Follow guidance in NRCS Agronomy Technical Note 190-AGR-10, Adaptive Management for Conservation Practices and the specific guide sheet for comparing new cover crop management techniques.

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