

Making the Most of Mixtures: Considerations for Winter Cover Crops in Temperate Climates

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Introduction

Cover crops can provide multiple benefits. For example, they can improve soil health, supply nutrients to cash crops, suppress weeds, help manage insect pests, produce forage, support pollinators and beneficial insects, and reduce water and air pollution. However, not all cover crop species provide the same benefits. How can you best reap the multiple benefits of cover cropping with so many species to choose from? To multiply and diversify your cover crop benefits, plant mixtures.

This article will describe some of the basic concepts to consider when planning a cover crop mixture. Selecting complementary species to meet different farm management objectives, timing planting and management correctly, and using effective establishment and termination methods are all important for successful cover crop mixtures. Information in this article is based on the research and experiences of a multidisciplinary team of researchers, educators, and farmers who have been evaluating cover crop mixtures in the northeastern United States. Most of our experience with cover crop mixtures is in organic feed crop rotations in temperate humid climates where cover crops are used during overwinter fallow periods. Despite the regional and cropping system specificity of our experience, many of the principles described in this article can be applied to a variety of farming systems and climates. We invite you to learn more about our USDA OREI-funded research and education project, [Multifunctional Cover Crop Cocktails for Organic Systems](#).

Tailoring a Cover Crop Mixture to Farm Management Objectives

Every farm is different. Even within one farm, management objectives for a given field and crop will vary based on weather, site location and history, crop rotations, and many other factors. The design of a cover crop mixture must, therefore, take into account the current and future management objectives for each field. Whether the goal is breaking up a plow pan, overcoming low fertility, knocking out a pernicious weed, or a combination of services, different cover crop mixtures and specific management approaches will be needed. The starting point for developing mixtures is understanding the strengths and weaknesses of individual cover crop species.

Cover crop strengths and weaknesses. Individual species of cover crops often excel at providing one or two functions, while also having specific drawbacks. For example, forage radish (*Raphanus sativus* var. *longipinnatus*) can suppress weeds and reduce compaction in the fall, but because it winter-kills, it does not provide a living root system or residue cover in the spring. Red clover (*Trifolium pratense*) captures nitrogen from the atmosphere, but may not suppress weeds when seeded in the heat of summer without a companion species. Cereal rye (*Secale cereale*) can stop nitrogen from leaching, but may deprive the following cash crop of nitrogen. Meeting multiple objectives while avoiding basic pitfalls may require combining several species. Tables 1 and 2 list many of the common cover crop species used in the northeastern United States, their relative ability to provide different services, known drawbacks, and recommended planting date windows.

Top 7 Reasons Farmers Use a Cover Crop Mixture Results from interviews with 47 farmers about why they planted cover crops on a total of 110 fields.

1. Reduces erosion
2. Increases soil organic matter
3. Increases yields for the following cash crop
4. Controls weeds
5. Reduces compaction
6. Scavenges nitrogen
7. Provides nitrogen for the upcoming cash crop

How to Make a Cover Crop Mixture

The following steps can help build a mixture that meets farmer objectives, avoids pitfalls, and takes advantage of the power of cover crop diversity. (Refer to Tables 1 and 2 as needed.) The finer points in this process, such as choosing complementary species and seeding rates, are discussed below.

1. Identify the top three desired cover crop services for a specific field or farm.
2. Identify the cover crop planting date and termination date that will define the cover crop growth window available in your rotation.
3. Pick a core set of cover crops that excel at providing the desired services (2-3 species) and that are adapted to the growth window available.
4. If possible, select species with complementary growth periods, growth forms, and nutrient acquisition strategies.
5. Identify the drawbacks from these cover crops, or “missing services” that they don't provide. If any have severe drawbacks, drop that species from the mix.
6. Make a list of cover crops that could account for the drawbacks or provide the missing services. Choose one or two that fit with your planting window and, ideally, are complementary with the core cover crop species identified above.
7. According to National Organic Program regulations, organic growers should use certified organic seed except “...non-organically produced, untreated seeds and planting stock may be used to produce an organic crop when an equivalent organically produced variety is not commercially available...” (§ 205.204). For more information see the eOrganic article [Sourcing Certified Organic Seed and the National Organic Program Regulations](#).
8. Determine the appropriate seeding mix and planting method, being sure to keep extremely competitive species at a low seeding rate.
9. Get planting!
10. Watch the cover crop growth and be sure to terminate at the right time. Pay special attention to cereal grasses that are about to become lignified or plants going to seed that could become weedy.
11. Observe the results and make adjustments in the species mix and seeding rates to achieve even biomass representation from all the species.

Building a Complementary Mix

The success of a cover crop mixture depends upon each species in the mix providing the desired services in the appropriate balance with other species in the mix. Achieving this balance can be difficult because certain species are highly competitive, causing the desired services of the less competitive species to go unrealized. Often, these services are tied to a cover crop's biomass production or the density of certain plant parts, such as taproots or flowers. For instance, legume cover crops with greater biomass and nitrogen content will supply more nitrogen, and a greater flower density in a cover crop stand will attract more pollinators. However, more is not always better. In some cases, excessive biomass production by species in a mixture may cause challenges for cover crop termination and incorporation, planting of the following crop, and may also reduce the efficacy of other species in the mix. Balancing the services provided by a mixture requires selecting species that are complementary in their growth periods, growth forms, nutrient acquisition strategies, and resources for pollinators and beneficial insects.

Complementary growth periods

Different cover crop species can have a variety of temporal growth periods. Some species have narrow or restricted seeding windows in the fall to achieve successful establishment. While some species will winter-kill due to cold temperatures, others will require termination early in the spring to avoid excessive growth, and yet others will require delaying termination later into spring to allow for sufficient growth. Navigating the maze of complementary growth periods is a sure way to hone down the list of cover crop species that will perform well together in a mix.

Begin by considering the date in the summer or fall when the cover crop can be planted. Generally, earlier planting dates will allow you to choose from more potential species. Then consider when you will terminate the cover crop, such as early, mid, or late spring, and select species that have similar optimum termination times. Tables 1 and 2 list recommended planting dates and optimum termination dates for each species.

Many temperate climate cash crop rotations—especially the common corn-soy rotation—greatly limit cover crop options, because the grain is harvested too late for many cover crops to be established. However, farmers with a strong desire to use cover crop mixtures can adjust their cash crop rotation to allow for more cover crop options. For example, including a small grain crop in the rotation allows late summer cover crop seeding after small grain harvest. Spring cover crop growth can be prolonged by pushing back cash crop planting dates and using crop varieties from shorter maturity groups. In addition, innovative methods such as inter-seeding, high-boy seeding, and aerial seeding can allow cover crops to establish during the cash crop window, and then grow rapidly when the cash crop is removed.

When the cover crop planting date is early enough to successfully establish winter-killed cover crop species, consider a mixture that includes both winter-killed and winter-hardy species. Rapid growth of the winter-killed species in the fall will increase nitrogen uptake, weed suppression, and erosion control in the fall. However, after winter-killing, some services provided by the cover crop begin to diminish. Without a living cover crop growing through the winter and into the spring, nitrogen scavenging and nitrogen fixation cease, and the opportunity to grow more cover crop biomass to build organic matter is lost. Having winter-hardy species in the mixture will help to maintain cover crop benefits throughout the winter and into the spring.



One example of a successful mixture with complementary growth periods is oats (*Avena sativa*), crimson clover (*Trifolium incarnatum*), and annual ryegrass (*Lolium multiflorum*). Oats grow quickly in the fall, suppressing weeds and scavenging residual nitrogen, but will winterkill with prolonged freezing temperatures. With an appropriate planting date and management, oats can even produce enough fall biomass to be harvested or grazed for forage. The crimson clover and annual ryegrass are moderately winter-hardy and will continue to grow in the spring in some climates, providing nitrogen scavenging, nitrogen fixation, and erosion control until termination in the spring. Annual ryegrass and crimson clover also have similar optimum termination times in spring. Variations on this mixture can be made by replacing oats with different winter-killed species, such as sorghum-sudangrass (*Sorghum bicolor* X *S. bicolor* var. *sudanese*) or forage radish based on farm management goals and planting date considerations. When mixing winter-killed and winter-hardy species, be careful that the seeding rates of the winter-killed species are kept low enough that the winter-hardy species are not smothered out in the fall (seeding rate suggestions are discussed in a later section).

A cover crop mixture of annual ryegrass, forage radish, and orchardgrass interseeded into standing corn using a modified high clearance drill. Photo credit: John Wallace.

Complementary growth forms

Different species in a cover crop mixture can compete with each other for space and light, reducing the services provided by the less competitive species. Selecting species with complementary growth forms helps to alleviate competition between species. Cover crop growth forms can be divided into several categories, including tall open canopies, short dense canopies, and vining (See Tables 1 and 2). Species with similar growth forms are likely to compete with each other, while species with differing growth forms are more likely to be complementary. Tall, open-canopied species are especially compatible with vining species as the tall canopied species creates a ladder on which the vining species can grow. It is important that species with tall, open canopies are not planted too densely, or they will shade out the understory species. It should also be noted that some cover crop species, such as cereal grains, will shift their growth form from a short dense canopy to a tall open canopy when maturing from vegetative to reproductive stages. One way to manage species that will compete with each other for space is to plant them in an

alternating row configuration. This practice is described in more detail in the [Methods to Establish Cover Crop Mixtures](#) section of this article.

As an example, cereal rye and crimson clover both have short dense canopies in the fall, so they are in competition for the same space. Replacing crimson clover with a vining species, such as Austrian winter pea (*Pisum sativum* subsp. *arvense*), would create a more complementary mixture. In a pea-rye mixture, the rye will shift from a short dense canopy in the fall to a tall open canopy in the spring, providing support for the vining pea.



This four-species mixture consists of species with complementary growth forms: cereal rye and canola transition from short dense canopies to tall open canopies in the late spring, Austrian winter pea is vining, and red clover remains short and dense. Photo credit: Mac Burgess.

Complementary nitrogen acquisition strategies

Legume cover crops can obtain nitrogen from both the soil and the atmosphere, while non-legume cover crops, such as grasses and brassicas, can only obtain nitrogen from the soil. Although legumes can take up soil nitrogen, they do so less aggressively than grasses and brassicas. Because low soil nitrogen levels can limit cover crop and cash crop growth, and excessive soil nitrogen levels can stimulate

weed growth and contribute to nitrate leaching, the level of soil nitrogen availability should be taken into account when planning the cover crop mixture. Sometimes it is beneficial to pair species with different nitrogen acquisition strategies, while at other times only a single cover crop type may be necessary.

For soil with low nitrogen levels, legume cover crops that can satisfy their nitrogen demand from the atmosphere will be most effective. For soils with excessive nitrogen levels, non-legumes that are aggressive at scavenging soil nitrogen should be used. A legume cover crop planted in a soil with high nitrogen levels will grow well, but will be less competitive against nitrogen-hungry weeds and will not prevent nitrogen leaching as well as a non-legume would. Conversely, planting a non-legume into a soil with low nitrogen levels will result in sub-optimal biomass production due to nitrogen deficiency. In soils with moderate nitrogen levels, a mixture of a legume and non-legume can work well, as the non-legume will take up the soil nitrogen, protecting it against leaching, while the legume fixes nitrogen from the atmosphere, adding nitrogen to the plant-soil ecosystem. If the nitrogen level of a soil is not known, planting a cover crop mixture can be a useful strategy, as the performance of the mixture will adapt to the existing soil conditions. When large amounts of soil nitrogen are available, non-legumes will be favored and legumes may not flourish. With low soil nitrogen availability, legumes will be favored. This dynamic tradeoff between grasses and legumes allows the cover crop to adapt to the nitrogen management service needed most.

Complementary resources for beneficial insects and pollinators

Many beneficial insects—for example predators, parasitic wasps, and bees—can benefit from nectar and pollen provided by flowering cover crops. If providing resources for conserving pollinators and other beneficial insects is desired, differences in flower morphology such as shape, size, and color will influence the types of beneficial insects that are attracted to a particular cover crop. For example, cover crops with flat, open flowers allow pollen and nectar resources to be available to all shapes and sizes of bees as well as insect natural enemies. However, the narrow, closed flower morphology of legumes is typically difficult for small bees and beneficial insects, e.g., parasitic wasps, to enter to obtain pollen and nectar. Therefore, to provide resources to a diversity of beneficial insects, cover crop mixtures containing a variety of flower morphologies may be required.

Flower density has a significant influence on the number of bees and other beneficial insects that are attracted to a planting, with greatest beneficial insect visitation to plantings with the highest number of open blooms per area. Therefore, a monoculture of a flowering cover crop will be more attractive at peak flowering than a cover crop mixture that contains a lower density of open flowers. However, cover crop mixtures may contain species that

flower at different times, extending the potential time that floral resources are available. Most importantly, to provide floral resources to beneficial insects, flowers must be open and available. Cover crop planting and termination windows may not allow for flowering species to bloom before the cover crop is terminated. If a crop rotation window does not allow the cover crop to flower before it must be terminated, then it may be feasible to leave strips of cover crops in the field for a few extra weeks to further support beneficial insects. However, management of the cover crop before seed set or a plan to manage volunteer cover crops resulting from those that set seed should be in place before allowing cover crops to flower. For other considerations when providing resources to promote natural enemies, such as optimal distances between insectary strips and crop fields, see the eXtension article [Farmscaping: Making Use of Nature's Services](#).

Non-flowering cover crops can also provide resources for beneficial insects, such as extrafloral nectar, refuge and overwintering habitat, and alternate prey. These resources are all vital in supporting predatory and parasitic insects and spiders. The presence of these resources is important in facilitating early season colonization of fields by beneficial insects that can more easily respond to establishing pest populations. It is important to remember that cover crops can host crop pests, serving as a “green bridge” between cash crops. Therefore, it is critical to maintain a good crop rotation that takes into consideration the potential insect pest and disease-causing organisms that may be shared by the cover crops in a mixture and the subsequent cash crop in your rotation.

Weed Suppression with Cover Crop Mixtures

One of the main ways that cover crops suppress weeds is by shading the soil, which reduces weed germination and growth. In our research in Pennsylvania, we have observed that cover crops that emerge quickly after planting and grow rapidly in the early fall will have low weed biomass in the spring. In our experience, rye, oats, radish, and canola can effectively out-compete weeds when planted in mid-August after wheat harvest. Red clover and Austrian winter pea are slower growing, however, and are often invaded by weeds, even though pea stands can eventually produce a large amount of fall biomass. It is also worth noting that nitrogen-deficient brassicas and gaps between



drill passes can allow weeds to establish. To create a weed-suppressive cover crop mixture, start with one or two species that will cover the soil rapidly, then add more species according to your other goals.

The figure left illustrates some of the important points about achieving good weed suppression with cover crop mixtures. The legumes red clover and Austrian winter

pea are slower to establish in the fall and can allow weeds to get a foothold (A, B). Under nitrogen-deficient conditions, canola growth is limited (C), reducing its weed suppression compared to canola with sufficient nitrogen available (G). A mixture of slow-growing legumes (D) will be no better at suppressing weeds than a slow-growing

legume monoculture. Grasses like oats and rye are excellent weed suppressors (E, F) but even a small gap between drill passes can create a spot for weeds to take root (F). A diverse mixture that includes a few fast-growing species will provide weed suppression while allowing for benefits such as nitrogen fixation and floral resources from the other species (H). *Photo credit: Charlie White*

Cover Crop Mixtures Adjust to Climate and Nitrogen Availability

At each site, total biomass and species composition was quite different based on the climate and nitrogen availability at the site. At warmer sites, canola was the dominant species in the mix while cereal rye dominated at the cooler sites. As nitrogen availability decreased, the presence of Austrian winter pea in the mixture increased. Red clover did not contribute substantial biomass to the mixture at any of the locations. Because you may not always know how many growing degree days will be left in the fall after you plant your cover crop, nor will you always know the nitrogen availability in every field at cover crop planting time, a species mixture can be one way to insure that something in the mix will be well adapted to the growing conditions that present themselves.







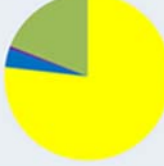

	Total Fall Biomass (lbs/ac)	Proportional Biomass Allocation	Growing Degree Days	Nitrogen Availability
Centre	2000	 	Low	Moderate
Berks	2700	 	Low	High
Lancaster	3200	 	Moderate	High
Montour	5700	 	High	Low

Photo credits: Mac Burgess (Centre County photo), Charlie White

Too Many? Too Few? How Many Species Are Just Right?

A central and yet unresolved question in the design of cover crop mixtures is “How many species should be in the mix?” In natural grasslands, it has frequently been observed that increasing the number of species in an area does enhance important ecosystem functions, but after a certain point, adding additional species no longer provides

additional benefits. Applying this idea to cover crop mixtures, we expect that selecting a small number (3 to 5) of complementary species and managing them to achieve even biomass production in the mixture will provide multiple cover crop functions. Beyond a certain number of species the return on our investment is likely to diminish. In other words, a carefully planned mixture of a few complementary species may provide the same or more cover crop services than a mixture with many species.

A major challenge in pinpointing the optimum number of species is the fact that cover crops, like other crops, have good years and bad years due to weather or management decisions necessary to meet other production goals. This leads to year-to-year differences not only in overall biomass production, but also in the contribution of each species to a cover crop mixture. Such differences can impact the extent to which a mixture provides the desired cover crop services. One way to buffer against the loss of a desired service is to increase redundancy in the mix with additional species that perform the same functions or exhibit similar growth characteristics. The redundancy present in higher diversity mixtures increases the likelihood that at least one species selected to fill a certain role can thrive—a type of insurance policy to assure that the mix will provide the services for which it was designed.

Methods to Establish Cover Crop Mixtures

The common methods of cover crop establishment, such as drilling and broadcasting, can be adapted for the successful establishment of cover crop mixtures. Some of the challenges and opportunities associated with establishing cover crop mixtures include achieving the correct seeding depth, preventing seed separation and settling in the drill box, selecting different row configurations, and determining the right seeding rate of each species in the mixture.

Seeding depth

Cover crop species vary in their optimum seeding depth from 0.25 to 1.5 inches. When species with different seeding depths are mixed together, there are several strategies that can be used to aid in successful establishment of each species.

Many drills have a large and a small seed box. The large box, sometimes called the grain box, is optimized for large-seeded crops and the drop tubes from the large box direct seeds to the deepest point in the furrow created by the disc openers. The small box, sometimes called the legume or grass-seed box, is optimized for small-seeded crops. The drop tubes from the small-seeded box can be directed to drop seed at the rear of the disc openers, resulting in a shallower seed placement. The drop tubes from the small box can also be left hanging straight down to dribble seed on the soil surface. Dribbling seed on the soil surface can be a useful strategy in tilled soil where a cultipacker will be used to firm the soil after seeding. Planting mixtures in one pass by splitting the species according to seed size and planting depth has been the most effective strategy at obtaining optimum seeding depths for various species in a mixture.

An alternative approach to managing depth of seed placement that has been proposed is to mix the seed of all species in the mix in one drill box and to set the seeding depth to approximately 0.75 to 1 inch. The suggestion has been made that in a mixture, the larger-seeded species planted to such a depth will break open the seed furrow as they germinate and allow the smaller-seeded species to then emerge. This approach sometimes works, and may be the only solution for drills with a single seed box. However, in our experience, this approach has occasionally led to sub-optimal stands of smaller-seeded species, particularly when the depth of the furrow is likely to change across a field due to variations in soil type and soil moisture.

A final approach that has been used, which is more time and equipment intensive than other approaches, is to seed the large-seeded species to depth with a drill and then to make a second pass with a broadcast seeder, broadcasting the small-seeded species onto the soil surface and then firming in the seedbed with a cultipacker. These two passes can also be combined into one using a custom-rigged tractor with a broadcast spreader on the front.



On the disc opener of this grain drill, the tube from the small seed box (smooth tube) deposits seed behind the disc opener for shallow seed placement. The tube from the large seed box (corrugated tube) deposits seed at the front of the disc opener for placement at the bottom of the furrow. Photo credit: Jim LaChance

Preventing seed separation and settling

Many people new to using cover crop mixtures are concerned that seeds of different sizes, mixed together in a drill box, will separate and settle as the drill travels across a field. Seed separation and settling has rarely been a significant issue in practice, however. The seed sizes that are most likely to separate from each other when mixed together are small round seeds and large round seeds. When a variety of different seed shapes and sizes are used in a mix, especially including oblong grass seeds, the packing arrangement becomes stabilized and seed separation is greatly reduced. Another approach to minimize seed settling would be to separate seeds into the small and large boxes of a drill, as previously discussed in the seeding depth section.

Selecting different row configurations

One of the opportunities that emerges when using cover crop mixtures is to plant different component species of the mixture in specific row configurations. This strategy can be used to minimize competition between species in a mixture. One common example is to plant forage radishes in alternating rows with a companion species. On a drill with 7.5" spacing between rows, a good row configuration might be one row of radish alternating with three rows of the companion, or two rows of radish alternating with two rows of the companion. Because forage radish has the tendency to outcompete other species in a mix, segregating the radishes and companion species into different rows allows the companion species to establish.

Alternating row configurations can easily be sown in one pass using a drill with two seed boxes. Simply place duct tape over openers inside each seed box to create the desired pattern and then place the set of seeds for each row type in the appropriate box. In a drill with one seed box, vertical baffles between openers, spanning front to back of the drill box, can be created with cardboard and duct tape. Fill each compartment created by the baffles with the appropriate seed to create the desired row configuration.



Alternating row configuration is one strategy to manage competition between species in a mixture. Here forage radish alternates with Austrian winter pea. Photo credit: Charlie White



To create an alternating row configuration, duct tape is used to seal off openers in the large and small seed boxes of a grain drill. The resulting pattern will plant two rows of the varieties in the large box alternating with two rows of the varieties in the small box. Photo credit: Charlie White

Determining seeding rates in the mixture

Determining appropriate seeding rates of each species in a mixture can be difficult. Start with the suggestions below, plant a small acreage, observe the results, and then make adjustments as necessary. Be aware that results will vary across fields, years, and climate zones.

Certain species are highly competitive against other species in a mix, including forage radish, canola (*Brassica rapa*), oats, sorghum-sudangrass, and cereal

rye. Seeding rates of these species must be dramatically reduced from monoculture seeding rates to prevent them from dominating the mixture. Seeding rates for these species in mixtures should be no more than 2 to 3 lb/A for forage radish, 3 to 4 lb/A for canola, 15 to 20 lb/A for sorghum-sudangrass, and 20 to 30 lb/A for oats or cereal rye.

Seeding rates for other grasses in a mixture can safely be reduced to between half and one-quarter of monoculture seeding rates to achieve a balanced stand with legumes and other broadleaf species. Legume components of a mixture, which tend to be weak competitors, are more safely kept near their monoculture rates to ensure establishment in the stand.

When two or more species that are functionally redundant are included in a mix with other types of cover crops, seeding rates of the redundant cover crop types should be reduced even further. For example, to determine seeding rates of the winter-hardy grasses such as annual ryegrass, cereal rye, and triticale (x *Triticosecale*) in a mixture with crimson clover and oats, first consider that the seeding rate for winter-hardy grasses should be reduced at least in half compared with a monoculture rate. Then, because the three similar species of grasses are functionally redundant, divide the half rate for each species by the number of redundant species, in this case 3, to obtain a final seeding rate in the mix. In this case, monoculture rates of 20 lb/A for annual ryegrass, and 120 lb/A for cereal rye and triticale would first be cut in half and then divided by 3, such that final rates of approximately 3.3 lb/A annual ryegrass, and 20 lb/A each of cereal rye and triticale would be used.

Example Seeding Rate Calculation

Species in the mix: Annual ryegrass, cereal rye, triticale, oats, crimson clover

Consider:

- Seeding rate for a winter-hardy grass should be reduced by one-quarter to one-half the monoculture rate
- Annual ryegrass, cereal rye, and triticale are three functionally redundant species of winter-hardy grasses.
- Seeding rate for functionally redundant species should be reduced again by the number of redundant species
- Legumes should be kept close to monoculture rate
- Oats and cereal rye are highly competitive species and should be kept below a threshold rate

Calculated seeding rates:

Annual ryegrass

20 lb/A in monoculture \div 2 for half-rate of winter-hardy grass \div 3 for functional redundancy = 3.3 lb/A in the mixture

Cereal rye

120 lb/A in monoculture \div 2 for half-rate of winter-hardy grass \div 3 for functional redundancy = 20 lb/A in the mixture

(Note: because this is a highly competitive species, double check that the calculated rate is below the recommended threshold)

Triticale

120 lb/A in monoculture \div 2 for half-rate of winter-hardy grass \div 3 for functional redundancy = 20 lb/A in the mixture

Crimson clover

12 lb/A in monoculture should be reduced only slightly to \approx 10 lb/A in the mixture

Oats

Because oats is a highly competitive species, the seeding rate should be less than 20-30 lb/A in a mix

Considerations when Terminating Cover Crop Mixtures

Just as a cover crop mixture must meet the specific needs of a cropping system, the appropriate timing and method of termination is often cropping-system specific. Generally, cover crops in organic systems can be terminated with various combinations of a moldboard plow, flail mower, disk, and/or cultimulcher. In organic reduced-tillage systems, a roller-crimper is typically used. Important management considerations regarding termination of cover crops include terminating at an optimum maturity stage, synchronizing maturation rates or planning for asynchrony, and managing soil moisture.

Determining the optimum maturity stage to terminate cover crops can be challenging because it often involves tradeoffs among the different benefits provided by cover crops. For instance, as grasses mature, the biomass increases dramatically, nitrogen concentration of the tissue declines and lignin levels increase. A grass that is allowed to grow to the pollen shedding stage can be challenging to incorporate into the soil, cause poor seed-to-soil contact when planting the following crop, and cause nitrogen immobilization as the cover crop decomposes. Incorporating large amounts of biomass can also stimulate some crop pests, such as seed corn maggot. On the other hand, allowing the grass to reach the pollen shedding stage can provide resources for beneficial insects and maximize organic matter inputs to the soil. Allowing legumes to grow to the flowering stage generally maximizes nitrogen accumulation of the cover crop, but allowing a legume to flower for too long can cause a decline in nitrogen content as nitrogen is transferred to maturing seeds. Allowing species such as hairy vetch (*Vicia villosa*) or canola to flower for too long may also result in viable seed set, possibly creating an undesirable seed bank in the soil. For example, in [Northeastern organic reduced-tillage systems](#), studies found that cereal rye/hairy vetch mixtures often required multiple roller-crimper passes to prevent seed production because of differences in the maturity timing of each cover crop. However, under a different management approach, maintaining a longer

flowering period before terminating the cover crop may be desired to provide resources to beneficial insects. Thus, the optimum maturity stage to terminate a cover crop will depend on specific objectives for the cover crop and constraints of the crop rotation and management, and may require balancing of any tradeoffs that arise.

The above examples illustrate why it is important to consider synchrony and/or asynchrony of certain species in a mix with regard to termination timing. The selection of complementary growth periods and forms in the species of a mixture will allow for uniform termination of all species; however, several strategies exist to manage asynchrony when it arises. For example, if a mixture of cereal rye and red clover is allowed to mature for too long, then the cereal rye can become excessively lignified, potentially leading to nitrogen immobilization in the following cash crop. One alternative termination strategy in this scenario is to flail mow at a height that primarily destroys tall rye biomass, while the understory of red clover continues growing until final termination. Alternatively, another example could be to switch the grass in your mixture from cereal rye to a later-maturing grass – like triticale (*x Triticosecale*), wheat (*Triticum aestivum*), or spelt (*Triticum spelta*) – thus increasing the likelihood of synchrony between the cover crops in the mixture, and reducing nitrogen immobilization that could occur from the incorporation of highly-lignified stems.

In addition to maturity considerations, cover crop termination decisions must also account for soil moisture. For example, the longer a cover crop grows, the greater the potential loss of soil water from cover crop transpiration, which may reduce cash crop yields in a dry year. In wet years, on the other hand, cover crops can help use up excessive soil moisture and help farmers get in the fields sooner. Similarly, cover crop residue left on the soil surface as a mulch can either keep soils cool and moist, delaying planting, or, depending on the weather conditions, can retain needed moisture. Adaptive management based on rainfall patterns and cover crop growth is crucial to optimize cover crop water use and retention.

Each species in a cover crop mixture can present unique complications regarding termination and, as mixtures often vary significantly across different geographies, soil types, and climates, it is likely that site-specific management of cover crop mixtures in any location will take several years of fine-tuning.

Conclusions

The benefits of cover crops have been long recognized, and in some cases using a cover crop mixture can enhance these benefits. By tailoring the selection of cover crop species to meet farm management objectives, understanding complementarity between species, and following some basic management guidelines, an endless array of cover crop mixtures can be designed and implemented in any farming system. As with any new endeavor, observing the results and making adjustments based on previous experiences are important keys to long-term success when using cover crop mixtures. Together, the collaboration of researchers and farmers can continue to unlock the potential of cover crop mixtures as a key tool for enhancing the multi-functionality, resiliency, and sustainability of cropping systems.

Table 1 Click for viewing or printing: [Characteristics, ability to provide various services, and recommended planting date windows for non-legume winter cover crops commonly used in temperate cropping systems.](#)

Table 2 Click for 2 for viewing or printing: [Characteristics, ability to provide various services, and recommended planting date windows for legume winter cover crops commonly used in temperate cropping systems.](#)

Additional Resources

- Clark, A. 2007. Managing cover crops profitably, 3rd edition. Sustainable Agriculture Network, Beltsville, MD. (Available online at: <http://www.sare.org/SARE-Nationwide/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition>) (verified 13 May 2015)
- Colley, M., and B. Baker. 2013. Sourcing certified organic seed and the National Organic Program regulations. [Online]. eXtension Foundation, eOrganic Community of Practice. Available at: <http://www.extension.org/pages/18338/sourcing-certified-organic-seed-and-the-national-organic-program-regulations#.VVP8vdpViko> (verified 13 May 2015)
- Finding the right mix: Multifunctional cover crop cocktails for organic systems. Research project. [Online]. Penn State College of Agricultural Sciences. Available at: <http://agsci.psu.edu/organic/research-and-extension/cover-crop-cocktails> (verified 13 May 2015)

- Green cover seed smart mix calculator. [Online]. An online tool to create custom seeding rate blends of many different species. The tool provides the monoculture seeding rate for each species and you can adjust seeding rates as a percentage of the monoculture rate. Available at: <https://greencoverseed.com/smartmix> (verified 13 May 2015)
- Improving weed and insect management in organic rotational no-till. [Online]. Research project. Penn State College of Agricultural Sciences. Available at: <http://agsci.psu.edu/organic/research-and-extension/rotational-no-till> (verified 13 May 2015)
- Zehnder, G. 2013. Farmscaping: Making use of nature's pest management services. [Online]. eXtension Foundation, eOrganic Community of Practice. Available at http://www.extension.org/pages/18573/farmscaping:-making-use-of-natures-pest-management-services#.VTBXT2Y4L_4 (verified 13 May 2015)

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Table 1. Characteristics, ability to provide various services, and recommended planting date windows for non-legume winter cover crops commonly used in temperate cropping systems.

Species	Optimum Termination Timing	Growth Form	Nitrogen retention	Nitrogen supply	Erosion Control	Alleviate Subsoil Compaction	Weed Suppression	Resources for Beneficial Insects	Habitat for Beneficial Insects	Forage Production	Planting date window, weeks before first killing frost ⁷	Potential Drawbacks
Cereal Rye (<i>Secale cereale</i>)	ES to MS	SD to TO	●	●	●	●	●	●	●	●	4 weeks prior to 6 weeks after	Narrow window for spring management due to rapid maturity progression in spring; Mature residues can immobilize nitrogen
Triticale (<i>x Triticosecale</i>)	MS	SD to TO	●	●	●	●	●	●	●	●	4 weeks prior to 6 weeks after	Mature residues can immobilize nitrogen
Wheat (<i>Triticum aestivum</i>)	MS to LS	SD to TO	●	●	●	●	●	●	●	●	4 weeks prior to 3 weeks after	Mature residues can immobilize nitrogen
Spelt (<i>Triticum spelta</i>)	MS to LS	SD to TO	●	●	●	●	●	●	●	●	4 weeks prior to 6 weeks after	Mature residues can immobilize nitrogen
Annual Ryegrass (<i>Lolium multiflorum</i>)	MS	SD	●	●	●	●	●	●	●	●	3 to 10	Mature residues can immobilize nitrogen
Oats (<i>Avena sativa</i>)	WK-25°	SD	● ¹	●	●	●	●	●	●	●	3 to 10	Highly competitive against other species in the mix
Sorghum-Sudan grass (<i>Sorghum bicolor</i> X <i>S. bicolor</i> var. <i>sudanese</i>)	WK-32°	TO	● ¹	●	●	●	●	●	●	● ⁴	8 to 12	Highly competitive against other species in the mix; high carbon residues can immobilize nitrogen
Forage Radish (<i>Raphanus sativus</i> var. <i>longipinnatus</i>)	WK-25°	SD	● ¹	● ²	● ³	●	● ⁵	●	●	●	3 to 10	Highly competitive against other species in the mix
Canola (<i>Brassica rapa</i>)	ES to MS	SD to TO	●	●	●	●	● ⁵	●	●	● / ● ⁶	3 to 10	Highly competitive against other species in the mix; can host pests of brassicaceous cash crops
Sunflower (<i>Helianthus annuus</i>)	WK-32°	TO	● ¹	●	●	●	●	●	●	●	10 to 14	

ES= Early Spring; MS= Mid Spring; LS= Late Spring; WK-32°= Winter-kills after light frosts; WK-25°=Winter-kills after hard freezes; SD = Short, dense; TO= Tall, open; V= Vining; ● = Excellent ability; ● =Moderate ability; ● = Limited to no ability.

Notes

¹Winterkilled species provide no nitrogen retention in the winter and spring. ²N released rapidly following winter kill of these species is subject to leaching losses.

³Forage radish provides excellent erosion control in the fall, but soil is left bare in spring after winterkilled residues decompose. ⁴Be aware of potential for prussic acid poisoning. ⁵Low soil nitrogen availability can limit the growth of brassicas, reducing their weed suppression capacity. ⁶Forage varieties of canola (also known as rape) can have excellent feed value.

⁷Planting date recommendations from Cover Crop Solutions, LLC when available and personal experience otherwise.

Table 2. Characteristics, ability to provide various services, and recommended planting date windows for legume winter cover crops commonly used in temperate cropping systems.

Species	Optimum Termination Timing	Growth Form	Nitrogen retention	Nitrogen supply	Erosion Control	Alleviate Subsoil Compaction	Weed Suppression	Resources for Beneficial Insects	Habitat for Beneficial Insects	Forage Production	Planting date window, weeks before first killing frost ⁴	Potential Drawbacks
Red Clover (<i>Trifolium pratense</i>)	LS	SD	●	●	●	●	● / ● ²	●	●	●	8 to 12 or frost-seeded into small grain	
Austrian Winter Pea (<i>Pisum sativum subsp. arvense</i>)	LS	V	●	●	●	●	●	●	●	●	2 to 10	
Crimson Clover (<i>Trifolium incarnatum</i>)	MS	SD	●	●	●	●	●	●	●	●	3 to 10	
Hairy Vetch (<i>Vicia villosa</i>)	LS	V	●	●	●	●	●	●	●	●	2 to 10	Hard seed can cause delayed germination in subsequent cash crops, becoming a weed
Fava bean (<i>Vicia faba</i>)	WK-25°	TO	●	● ¹	●	●	●	●	●	●	8 to 10	Can build large populations of potato leafhopper, <i>Empoasca fabae</i> .
Sunnhemp (<i>Crotalaria juncea</i>)	WK-32°	TO	●	● ¹	●	●	●	●	●	● / ● ³	10 to 14	
Soybean (<i>Glycine max</i>)	WK-32°	SD	●	● ¹	●	●	●	●	●	●	10 to 14	Can build populations of cash crop soybean pests

ES= Early Spring; MS= Mid Spring; LS= Late Spring; WK-32°= Winter-kills after light frosts; WK-25°=Winter-kills after hard freezes; SD = Short, dense; TO= Tall, open; V= Vining; ● = Excellent ability; ● =Moderate ability; ● = Limited to no ability.

Notes

¹N released rapidly following winter kill of these species is subject to leaching losses. ²When frost-seeded into a small grain in late-winter, red clover provides excellent weed suppression after the small grain is harvested. When seeded in the summer, red clover is slow to establish and prone to weed invasions. ³Some varieties of sunnhemp have high levels of alkaloids, which can be poisonous to livestock. The variety ‘Tropic Sun’ was bred to contain low alkaloid levels and is palatable to livestock. For optimum forage quality, sunnhemp should be harvested within 30 days of planting, otherwise crude protein levels drop. ⁴Planting date recommendations from Cover Crop Solutions, LLC when available and personal experience otherwise.