WERA-103

Cover Crop Management in Semi-Arid Regions: Effect on Soil and Cash Crop

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Cover crop diversity over time or with mixed-species plantings is desirable to provide multiple cropping system benefits. Photo by Meg Housman.

Fallow-based cropping systems in semi-arid regions have been profitable and often less risky than recrop; however, their use is damaging to soil health and may limit long-run profitability. Cover crops can reduce summer fallow while possibly improving soil health. This article addresses cover crop management impacts on soil organic matter, soil water and N, and subsequent cash crop yields and grain protein concentration. Earn 1 CEU in Soil & Water Management by reading the article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/856.

Fallow-based cropping systems in semi-arid regions have been profitable and often less risky than recrop; however, their use is damaging to soil health and may limit long-run profitability. Soil health goes beyond nutrient levels and is critical for agroecosystem sustainability (Moebius-Clune et al., 2016). Cover crops can reduce summer fallow while possibly improving soil health. Improvements in soil health as measured by soil health indicators are unproven in semi-arid regions where cover crop biomass is low and stored soil water use by cover crops can reduce subsequent crop yield and residue. It is also often assumed that diverse cover crops are better for soil health than single-species cover crops, yet this is unproven in the Northern Great Plains.

Many cover crop benefits, such as stabilizing soil, increasing water-holding capacity, promoting microbial activity, and reducing erosion are a direct result of increasing both above- and belowground organic matter. Another important function of cover crops is increasing plant-available nitrogen (PAN, organic matter N that readily becomes plant available) and improving nitrogen (N) use efficiency. Producers can manipulate cover crop residue amount and quality by selection of cover crop species and termination timing. This article addresses cover crop management impacts on soil organic matter (SOM), soil water and N, and subsequent cash crop yields and grain protein concentration. The authors' focus is on cover crops planted as summer fallow replacement or partial summer fallow

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Adding legumes can provide necessary N to increase cover crop biomass in low-N soils. This photo shows nodules from a legume cover crop as well as an earthworm. Source: USDA-NRCS Montana.

replacement in the Northern Great Plains. Grazing of cover crops may change soil response, wheat yield and protein, and economics, but grazing is not included in this article.

Cover Crop Diversity

Biomass amount and consistency of production, soil N contribution, and water use are all important considerations when selecting cover crops. It is unlikely that a single cover crop can fulfill all desired functions. "Ideal" species and mixes depend on the location and the year. Until more studies are completed, advice from experienced cover crop growers and on-farm strip trials might be your best resources.

A theory based on ecological principles in native perennial systems and research in other regions suggests cover crop mixtures improve soil properties more than single-species cover crops (Malezieux et al., 2009). The belief is that mixes can provide: (1) both high residue from species that produce large amounts of biomass as well as available N from species with low carbon-to-nitrogen ratios (C:N) and (2) more efficient water and nutrient use by cover crops because of different rooting habits. In semi-arid regions with unreliable precipitation, the key is to select single or mixed species with reliable and acceptable biomass production (Khan & McVay, 2019). Cover crop mixes may increase the chance that at least one species in the mix will emerge and grow. However, the greater expense of many cover crop mixes compared with a well-suited single species may not be justified (Nielsen et al., 2015).

Crop diversity over time (different crops each year) is an alternative to planting cover crop mixes. Diverse crop rotations provide many benefits to soil health and improved crop yields (Kirkegaard et al., 2015). They are outside of this discussion on cover crop diversity.

Timing

Timing of seeding should be selected to optimize growth based on climate, so for cool-season cover crops as partial- to full-fallow replacement in the Northern Great Plains, this generally means seeding in early to mid-spring. Spring-seeded cover crops can be terminated anytime between early summer to frost kill for partial- or full-fallow replacement. In most Montana dryland systems, early- to mid-season termination is strongly recommended to minimize soil water depletion for the next crop (Miller et al., 2006). Terminating cover crops by boot or early-pod stage has the added benefit of capturing high root biomass. Roots are an important source of long-term carbon toward building SOM. Even though shoots may produce two to three times more biomass than roots, root carbon stays in the soil 2.5 times longer than shoot carbon (Rasse et al., 2005). Root biomass peaks at boot stage in small grains. In oilseeds and pulse crops, root biomass reaches around two-thirds maximum biomass by the early-flower stage and peaks at late flower (Gan et al., 2009; Liu et al., 2011).

Late-season cover crops can "catch" residual soil N and provide some improved soil cover for erosion control before winter. They are not common in dryland systems in semi-arid regions because of highly unpredictable precipitation for establishment (Liebig et al., 2015). Late-season cover crops can be: (1) spring crops planted in late summer and terminated by frost or (2) winter-hardy crops that are terminated either before spring planting or early to mid-summer as partial summer fallow replacement.

If soil moisture is less of a limiting factor (e.g., irrigated systems), more soil improvements are realized with full- rather than partial-season and over-winter than spring cover crops (Liebig et al., 2017; Miller et al., 2011). In a northern Montana dryland system, winter pea (relative to spring pea) grown as a partial summer fallow contributed greater soil N, produced higher residue and had less weed biomass, used less soil water, and increased subsequent winter wheat grain yield and protein concentration (Miller et al., 2011). However, low fall moisture, winter kill, or soggy spring soil are obstacles to growing winter pea in Montana (Miller, personal communication).

In most Montana dryland systems, early to mid-season cover crop termination is strongly recommended to minimize soil water depletion for the next crop. Source: USDA-NRCS Oregon.

Over-winter cover crops and residue from full-summer cover crops may increase over-winter moisture capture. Over four winters in North Dakota, with 3.4 inches average over-winter precipitation, fallow lost 0.2 inches of water over winter in the top 4 ft of soil, short grain stubble gained 1.5 inches, perennial mix stubble gained 2.5 inches, and full-season summer mixed cover crop stubble gained 2.9 inches (Staricka, 2019). Such over-winter snow capture depends on tall standing stubble.

Residue Quality

Plant residue quality is influenced by crop species, growing conditions, and plant maturity at time of termination. Here we characterize quality by the C:N, with high quality having relatively more N, so a lower C:N. Cereal grains and mature plants have relatively high C:N while legumes and young plants have low C:N. Peas terminated near first flowering, as well as grasses terminated at the same time, had low C:N (Housman, 2016; Tallman, 2014).

A diversity of C:N residue inputs is ideal. Low C:N residue promotes high microbial activity and rapid release of plant nutrients. However, this can lead to N leaching loss if no crop is in place to use it (Tonitto et al., 2006). Higher C:N residue will result in a slower release of N that can better match crop N needs but can result in N tie-up. A balance between residue build up and decomposition can be accomplished through selection of cover crop species and termination timing.

Soil Organic Matter

Cover crops can build SOM if enough residue is returned by both the cover crop and the following cash crop. A 10-year Montana study (no-till) and a 10-year Saskatchewan study (no-till and conservation till) found that SOM was maintained with about 1.8 tons/ac/year of dry aboveground biomass input in silt loam soils (Figure 1; Shrestha et al., 2013). The 1.8 tons/ac/year threshold is an annual average over a multi-year cropping system, meaning the cover crop plus cash crop stubble. For example, 36 bu/ac continuous winter wheat, 72 bu/ac winter wheat-fallow, or 1 ton cover crop biomass plus 31 bu/ac winter wheat the following year are rotations that could lead to 1.8 tons/ac/year biomass.

These production levels can be challenging to meet, especially the crop–fallow yield, which is why it is nearly impossible to build SOM with fallow in rotation. The slope of the SOM versus residue input line (Figure 1) shows that for each ton of aboveground residue, about 0.4 tons of SOM is formed, and the remaining 0.6 tons is used as energy by soil microbes. Below

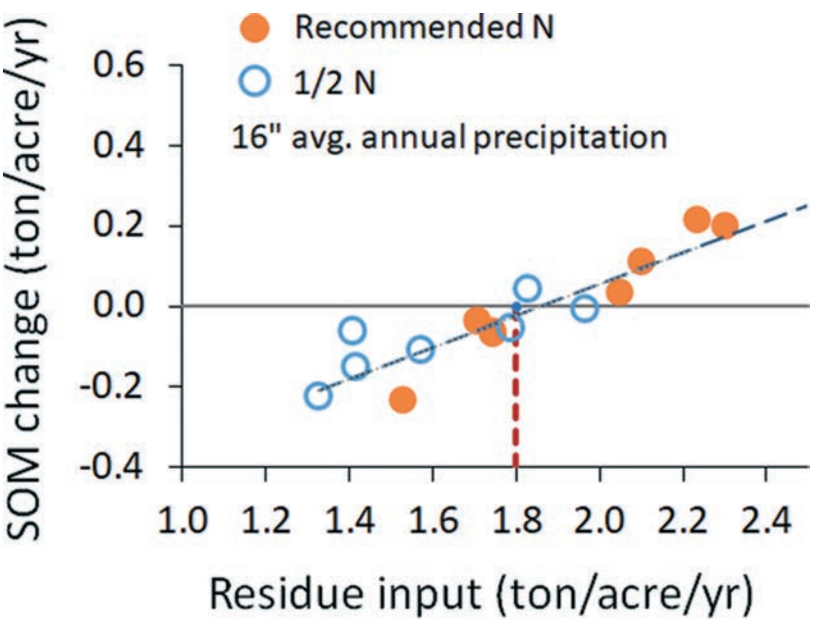

Figure 1. Average annual soil organic matter change over 10 years relative to annual aboveground residue input at two N fertilization levels (Engel et al., 2017).

about 1.8 tons/ac/year, residue input is less than loss of new plant residue plus SOM from the system through decomposition. Both studies were in relatively high production regions of the Northern Great Plains. It is likely that in drier locations, the break-even amount is lower than 1.8 tons/ac/year because of lower decomposition rates of SOM and residue.

While it might be tempting to terminate cover crops later to maximize biomass returned, grain yield and profit will likely be hurt with this approach. In Montana studies, pea and two- to eight-species mixed cover crops terminated by first bloom in 13 site-years produced an average 9 bu/ac less wheat for each ton of cover crop biomass (Tallman, 2014; Housman, 2016; Miller, unpublished data; O'Dea et al., 2013). This is a reduction of 0.45 tons winter wheat residue per acre (and substantial revenue). If cover crops are terminated late to increase biomass, they will likely reduce subsequent crop yield and residue proportionately more than 9 bu/ac per ton of cover crop. It can happen that the loss of subsequent stubble is similar or greater than the increase in cover crop biomass gained by letting the cover crop grow longer. The net two-year residue is then no higher than if the cover crop is terminated early while later termination certainly caused yield and economic loss.

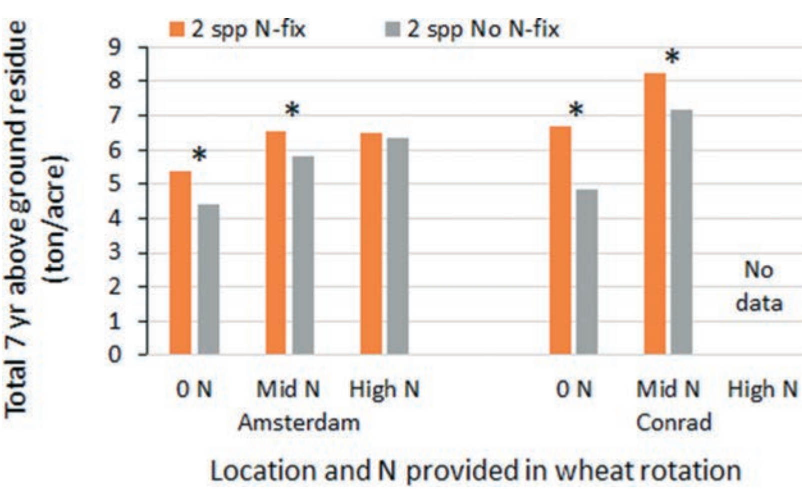

Figure 2. Total aboveground biomass from cover crop and alternate-year wheat residue at two Montana locations and different levels of wheat N fertilization. The cover crop was either two species of a pulse crop or three different two-species mixes without a pulse crop. * indicates 99% confidence of a difference between cover crops within a location and N level (Miller et al., unpublished data).

In dry years or locations, there is the risk that even early terminated cover crops cannot produce enough biomass to offset the loss of small-grain stubble the following year (Miller et al., 2006; O'Dea et al., 2013).

If increasing SOM is the major goal of a cover crop, good agronomic practices such as N, phosphorus, and sulfur management should not be ignored (Wuest & Reardon, 2016). For example, reducing N to half the recommended rates across several cropping systems generally reduced residue inputs to levels leading to SOM loss (Figure 1). However, at two drier cover crop sites (12- to 14-inch annual precipitation), fertilizer N rate did not affect SOM (Jones et al., unpublished data), likely in part because water limited biomass more than N.

At two Montana locations, the total residue returned by alternating early terminated cover crop with wheat over four cycles was 10 to 40% greater when cover crops contained legumes. Including legumes was more important when the intervening wheat rotation received little or no N fertilizer (Figure 2). This agrees with others who found adding legumes can provide necessary N to increase cover crop biomass in low-N soils, but the N benefit of adding legumes to a mix disappears in high-N soil (Hayden et al., 2014).

In general, the number of species does not greatly affect average cover crop biomass (Miller, unpublished data; Khan & McVay, 2019). A well-suited single-species cover crop generally produces more biomass than a multi-species mix (McGuire, 2015). However, in mixed cover crops, a larger number of species can provide more reliable biomass production than a small number of species; in other words, there's a better chance something will grow well and that biomass amounts will be more consistent across growing seasons. Among four unique six-species blends, the cumulative biomass produced over three growing seasons varied from 92 to 108% of their average. The cumulative biomass of four unique two-species blends varied from 75 to 125% of their average, but the mixes did not produce more biomass than pea alone (Miller, unpublished data).

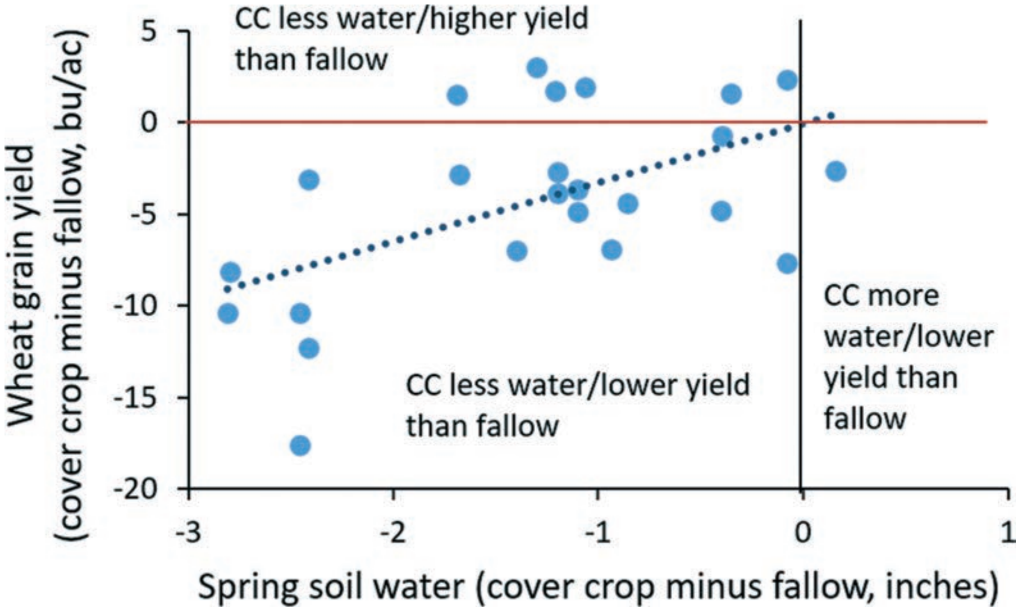

Figure 3. The difference in wheat grain yield after a cover crop (CC) compared with fallow relative to the difference in spring soil water (to 3-ft depth) after a cover crop compared with fallow. Cover crops were terminated at the first-flower, full-bloom, or pod stage. The zero on either axis means there was no difference between cover crop and fallow. For example, the value (spring soil water, grain yield) (−1, −7) means the cover crop had 1 inch less soil water the following spring and produced 7 bu/ac less wheat than fallow (Burgess, 2012; Burgess et al., 2014; Miller, unpublished data; O'Dea et al., 2013; Zentner et al., 2004).

Soil Water and Grain Yield

In dry climates, early termination is critical for protecting soil water and subsequent crop yields. The water transpired to produce biomass is only partially offset by reduced evaporation, snow catch, and potentially increased water-holding capacity from slightly increased SOM. In semi-arid regions of Montana, transpiration by cover crops during plant growth tips soil water balance firmly to the negative. Lower spring soil water after cover crops generally leads to lower wheat yield the following year (Figure 3). Haying, tillage, or chemical termination at late bud to first bloom, rather than waiting for maximum biomass near full pod, conserves soil water and has less of an effect on subsequent wheat yields (Figure 4; Allen et al., 2011).

The number of species in a cover crop and whether or not legumes are included generally does not appear to influence wheat yields when fertilized near optimum levels for yield. On two Montana sites, the cumulative wheat yield over three two-year cover crop–wheat rotations were the same following an eight-species mix containing legumes or spring pea alone (Miller, unpublished data). Also, over 13 site-years, wheat yields were similar following both legumes and non-legume cover crops and equal or less than after fallow (Miller et al., 2016; Miller, unpublished data).

In soils with limited water-holding capacity (high gravel content and/or less than 3 ft to gravel), wheat yields may be the same or higher following cover crops than fallow (Chen et al., 2012) because fallow doesn't store much water. Also, any small addition of SOM by a cover crop should increase water-holding capacity.

Nitrogen and Protein

Plant-available N is directly related to the total amount of N provided by plant residue and the rate of decomposition. Tillage increases residue decomposition and N release (Burgess et al., 2014) as does higher soil moisture and temperatures.

Plant-available N is high when legumes comprise 75 to 100% of the cover crop and low if legumes are 25% or less (Sullivan & Andrews, 2016). A minimum of 40% legume in a mixture was suggested to prevent N tie-up in soils following cover crops (Kuo & Sainju, 1998). Although legume cover crop residue has low C:N and decomposes rapidly, N in pulse crop residue may supply N for grain planted three years later (Grant et al., 2016).

Although pulses can fix N, they are good soil N scavengers, so they do not always increase PAN. Also, in cool semi-arid regions, the release of PAN from a pulse cover crop can be too slow to supply N for early cash crop growth (Thomas et al., 2017). After single two-year rotations of a pulse cover crop or fallow and wheat, soil nitrate-N levels were lower (29–56%) at both winter and spring wheat seeding time with the pulse cover crop than fallow (O'Dea et al., 2013). However, some Montana studies have found that spring soil nitrate-N can be equal or greater after winter pea than fallow, especially if the pea is terminated or hayed by early flower (Miller et al., 2006) and N availability increases after more pea cover crop rotations (Miller, unpublished data; Jones, unpublished data).

To maximize PAN, terminate cereal cover crops before stem elongation (jointing). Cereals terminated at flag leaf provide little PAN and if terminated after flag leaf, N in residue becomes tied up by microbes (immobilized). Growers should terminate

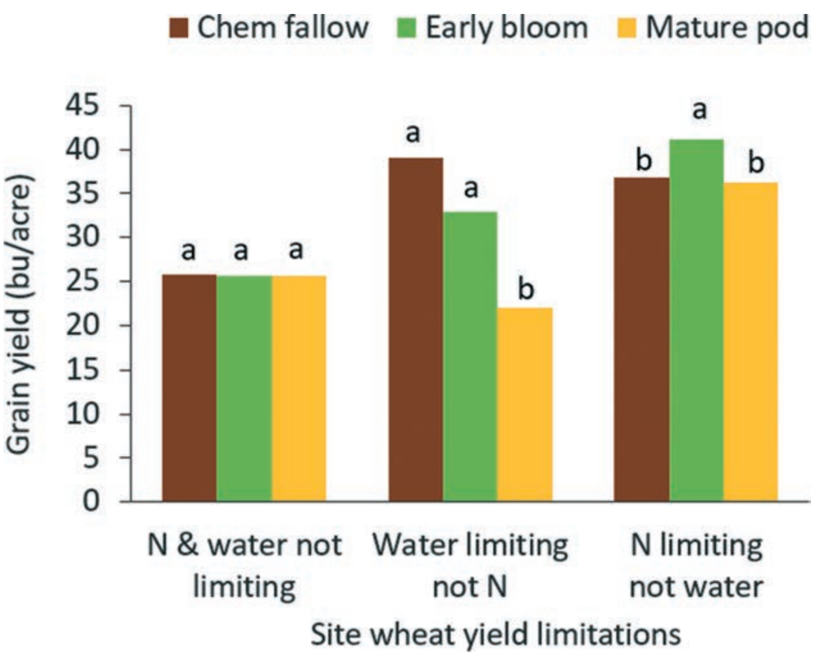

Figure 4. Spring wheat yields are higher following pea cover crop terminated at early bloom than mature pod when either water or N is limiting (Miller et al., 2006). Letters denote differences within a site, with 90% confidence.

legumes at bud stage for maximum PAN. Legumes terminated early not only have lower C:N, they leave more PAN for the next crop than when terminated at maturity (Miller et al., 2006).

Several longer-term studies suggest that N benefits to wheat may be realized only after multiple years of legumes in rotation (Campbell et al., 1992; Allen et al., 2011), especially in no-till systems (Schoenau & Campbell, 1996). O'Dea et al. (2015) found potentially mineralizable N after four cycles of pulse cover crop alternating annually with wheat was 1.5 times that found in fallow–wheat systems.

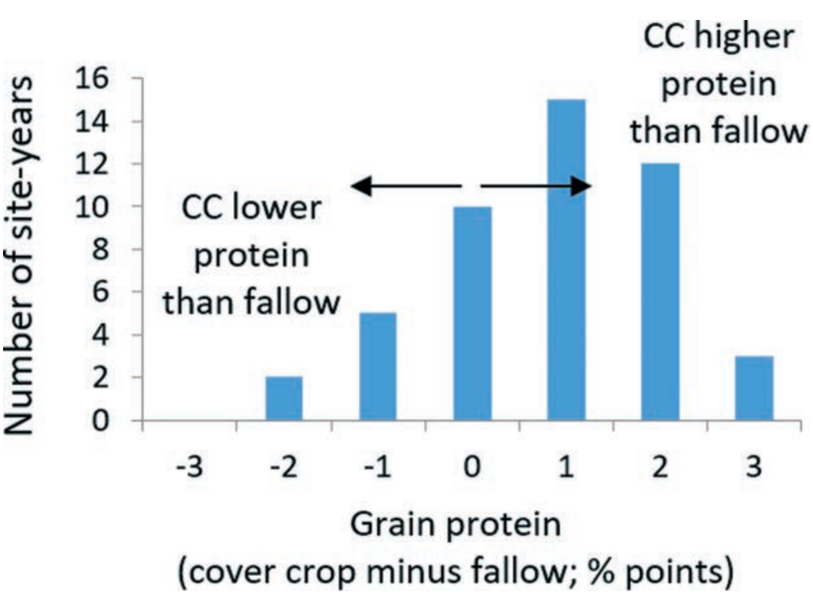

Figure 5. The number of times small-grain protein was lower or higher following a cover crop (CC) than fallow for 47 site-years. Positive protein means the cover crop produced higher protein than fallow (Allen et al., 2011; Burgess, 2012; Housman, 2016; Miller et al., 2016; Miller, unpublished data; O'Dea et al., 2013; Tallman, 2014; Zentner et al., 2004).

A lack of immediate N benefits to yield could be discouraging. However, cover crops that include a legume can increase wheat grain protein more often than not (Figure 5) and with fewer rotations than needed to benefit grain yield. A Montana study found small-grain protein was consistently equal between the cover crop and fallow after two rotations of a lentil cover crop while grain yields were not equal until after three rotations (Allen et al., 2011). In a long-term Montana study, wheat grain protein was consistently the same as or greater after early terminated pea than fallow (Miller et al., unpublished data). Both winter and spring wheat protein reached or exceeded the protein cutoff level following a pea cover crop despite receiving 54 lb N/ac less fertilizer on average every year than wheat after fallow.

Since N contribution from legume cover crops can be highly variable, soil nitrate-N levels should be tested and fertilizer N rates adjusted following cover crops. Because legume cover crops increase fertilizer N recovery (Rick et al., 2015) and supply N in the long term (Allen et al., 2011), eventually fertilizer N rates can be substantially reduced (Zentner et al., 2004). This should minimize nitrate leaching (Zentner et al., 2006) as well as soil acidification from ammonia-based N fertilizer (Jones et al., 2019).

Conclusion

Cover crop diversity over time or with mixed-species plantings is desirable to provide multiple cropping system benefits. If growing plant residue to increase SOM is the goal, using a multi-species mix of cover crop may supply a more reliable and consistent amount of biomass but generally does not produce more biomass than a well-adapted single species such as pea. At low-to-moderate N fertilizer levels, cover crops that contain legumes generally produce high biomass, leading to increases in SOM as well as providing PAN. Early- to mid-season termination of summer fallow replacement cover crops is suggested to minimize soil water depletion and subsequent small-grain yield losses. To gain SOM in semi-arid regions, the cover crop–cash crop rotation should produce at least 1.8 tons/ac of aboveground dry

Source: USDA-NRCS Montana.

biomass per year. The biomass gained by allowing a cover crop to grow to full maturity may not offset the wheat stubble loss due to lower small-grain yields the following year because of low soil water. Generally, N from legume cover crops increases wheat protein while it may take several legume cover crop rotations before the added N benefits wheat grain yield. Soil N levels should be tested and fertilizer N rates adjusted following cover crops.

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1. It takes longer to see soil benefits from cover crops grown as a partial-fallow replacement in semi-arid regions than in more humid areas because semi-arid areas

- **a.** have more shallow soils.
- **b.** have faster decomposition of plant residue.
- **c.** produce lower biomass amounts.
- **d.** have fewer cover crop options.

2. Many of the soil health benefits of cover crops come through their contribution of plant residue to the soil. Which of the following is true?

- **a.** Mixed-species cover crops are more likely to produce maximum biomass than single species.
- **b.** The cover crop's belowground root growth is more important than aboveground plant biomass in contributing to soil organic matter.
- **c.** Based on regional studies, the average annual residue input on a given field should be more than 1.8 ton/ac/yr to increase soil organic matter.
- **d.** The choice between cover crop biomass produced and water use always tips in favor of biomass production regardless of soil type.

3. Diverse cover crops rather than pea alone

- **a.** dramatically increased biomass returned.
- **b.** substantially increased soil organic matter.
- **c.** greatly increased subsequent crop yield.
- **d.** had relatively little effect on biomass or subsequent crop yield.

4. Increasing the number of species in a cover crop planting

- **a.** will increase subsequent wheat grain protein.
- **b.** enables the producer to successfully fulfill all cover crop functions in a single cover crop planting.
- **c.** may provide more reliable and consistent biomass production over several years than two-species mix cover crops in the Northern Great Plains.
- **d.** uses less soil water than pea alone as a cover crop.

5. Early rather than late termination of cover crops

- **a.** consistently reduces total rotation residue (cover crop plus cash crop) returned.
- **b.** is not recommended.
- **c.** reduces grain protein of the following crop.
- **d.** results in more grain yield of next crop because more soil water is conserved.

6. Termination of cover crops by first bloom

- **a.** is more important in deep silt, clay, and loam soils than shallow, gravelly soils to reduce subsequent wheat yield loss.
- **b.** will reduce N fertilizer required to produce the same wheat yields as if following fallow.
- **c.** severely limits the amount of root biomass contributed to the system by the cover crop.
- **d.** is suggested for fall- but not spring-planted cover crops.

7. Advantages of legume cover crops over non-legume cover crops to the following crop's yield

- **a.** are generally seen after one cycle.
- **b.** increase over time.
- **c.** are only observed with late termination.
- **d.** are non-existent in semi-arid regions because of water limitation.

8. A healthy, well-established winter pea cover crop

- **a.** often results in less plant-available nitrogen because winter pea has lower C:N ratios than spring pea.
- **b.** results in high amounts of plant-available N for a spring cash crop if terminated immediately before spring crop planting.
- **c.** produces more plant-available nitrogen and plant residue than spring pea when both are grown as partial summer fallow.
- **d.** is only limited by the narrow planting time window between wheat harvest and winter freeze.

9. Using a legume as cover crop or including a legume in a cover crop mix

- **a.** generally increases wheat protein, and benefits to protein occur after fewer rotations than benefits to wheat grain yields.
- **b.** helps increase cover crop biomass regardless of soil N levels.
- **c.** reduces N fertilizer required for wheat production after a single cover crop rotation compared with fallow.
- **d.** will only supply soil N if the legume makes up more than 75% of the cover crop biomass.

10. Plant-available N for the next year's wheat crop

- **a.** is generally higher in the spring after a single partial-fallow cover crop rotation than fallow.
- **b.** is high when legumes comprise 75 to 100% of the cover crop and low if legumes are 25% or less.
- **c.** is at low risk of being lost to leaching if the soils are warm and moist after cover crop termination.
- **d.** is only increased if the cover crop is incorporated by tillage rather than chemically terminated and left on the soil surface.