

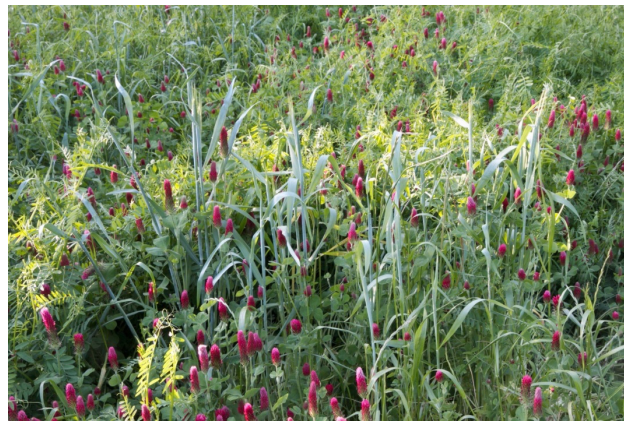
# USING COVER CROPS TO IMPROVE WATER QUALITY

## What are cover crops?

Cover crops are plants used to protect and improve the soil at times when cash crops are not being grown. They are commonly used to improve soil health and fertility, as well as protect the soil from erosion during the cash crop off-season. Although they can be integrated into any cropping system, their impact could be particularly profound in areas with a long off-season, like the Corn Belt. Crop fields in the Midwest in a corn/soy rotation typically only have living vegetation for four to five months a year, and crop roots are only robust for two to three months. That leaves the soil with reduced ability to absorb nutrients and leaves it vulnerable to erosion for most of the year, a prime recipe for water quality degradation. Cover crops enable farmers to keep fields covered with living vegetation throughout the year. The most common cover crops are grasses and small grains like cereal rye and wheat, brassicas like mustard and radishes, and legumes such as crimson clover and hairy vetch.

## Current use of cover crops

Cover crops are hardly a new idea, having been used in some areas for centuries. Thomas Jefferson and George Washington both used cover crops to manage erosion and soil fertility. Recent innovations in planting technology, however, as well as herbicides, have made cover crops easier to integrate into modern agriculture. New species and varieties of plants are being successfully used as cover crops, such as radishes, and there are still many more to test. The acres under cover crops have been steadily increasing; a national SARE/CTIC survey found farmers reported increasing their cover crop acres by 15 percent per year from 2012 to 2016.<sup>1</sup> Aggressive promotion of cover crops by the state of Maryland,



A variety of plant species are used as cover crops, sometimes in mixes such as the planting of cereal rye, hairy vetch, and crimson clover above. (Photo credit: R. Myers)

largely out of concern about water quality and the Chesapeake Bay, have boosted cover crop acres considerably there, leading to over half the corn and soybean fields being planted with cover crops in 2016. Indiana has also encouraged cover crops and boasted 970,000 acres in 2017.<sup>2</sup> Nationally, 10.3 million acres of cover crops were used in 2012.<sup>3</sup> It is expected there will be over 20 million acres of cover crops planted by 2020.<sup>4</sup> There are several incentive or cost-share programs for cover crops at the national and state level. The National Resource Conservation Service (NRCS) provides payments for cover crops under its EQIP and CSP programs.

Farmers use cover crops for a variety of reasons, and different cover crops provide different benefits for water quality management and crop production. Concern over erosion is a particularly common reason for adopting cover crops and this is reflected in the prevalence of quick-establishing cool season grasses as cover crops. Of these, cereal rye is the most popular; it is most often planted after corn in a corn/soybean rotation. Cereal rye reliably establishes thick stands, is readily terminated by herbicide application or mechanically, and the seed is fairly affordable. Wheat, oats, triticale and annual ryegrass are used in a similar way. In addition to erosion concerns, some farmers are motivated to use cover

crops to scavenge soil nutrients or fix nitrogen. For example, both organic and conventional farmers who use cover crops will often incorporate a nitrogen-fixing legume like hairy vetch or crimson clover. There is also growing interest in utilizing cover crops for livestock. Accordingly, high quality forage crops like forage rape and radish are quite common. Although not as significant in terms of acres, warm season cover crops like buckwheat and sorghum-sudangrass are used in vegetable systems or in more diverse row-crop operations to manage weeds and soil health. Increasingly, diverse mixes of cover crops are being used to take advantage of the differing benefits that a variety of species offer. The following material details how cover crops can improve water quality.

## How can cover crops improve water quality?

Sediment, nutrients, and agrochemicals all affect water quality near and sometimes far from agricultural fields. Erosion, runoff, and leaching are the primary culprits. Cover crops can ameliorate all three by protecting soil and promoting soil health. The main mechanisms by which cover crops protect water quality are listed below and then described in more depth in the following sections.

- Erosion
- Rainfall infiltration
- Soil water holding capacity and organic matter
- Nutrient runoff
  - Impact on nitrogen
  - Impact on phosphorous and micronutrients
- Agrichemicals

### Erosion

Eighty years after the Dust Bowl, erosion remains one of the greatest challenges to long-term agricultural production, public health, and food security in the United States. Erosion strips land of its valuable topsoil, which can lead to yield losses even in the age of synthetic fertilizers. Erosion contributes to poor water quality as sediments flow out of fields and into waterways, transporting

fertilizers and pesticides along with the eroded soil particles.

In a review of almost 60 years of cover crop and erosion research Langdale et al. (1991) found that cover crops reduced erosion from 47 to 96 percent in the United States. The other agricultural practice that can dramatically reduce erosion is no-till.<sup>5</sup> Cover crops and no-till combined can reduce erosion even more, often by over 74 percent.<sup>6,7</sup> Erosion on agricultural fields is inextricably tied to rainfall infiltration and soil water holding capacity. The effect of cover crops on infiltration and water holding capacity and the mechanisms by which they do so are discussed below.



**If planted in a timely fashion, cover crops can achieve substantial growth in fall as shown in this photo of rye and radish taken in early November in Indiana. (Photo credit: R. Myers)**

### Rainfall infiltration

One way to prevent erosion is to encourage rainfall to infiltrate the soil rather than run off a field and carry soil, nutrients, and pesticides with it. There is extensive evidence that cover crops can increase rainfall infiltration rates in a variety of cropping systems. Infiltration was 55 to 66 percent greater on fields with a hairy vetch cover crop than on fallow fields in Georgia.<sup>8</sup> Oat/vetch cover crops increased infiltration by 13 percent on tomato fields and from 37 to 147 percent in almond orchards in California.<sup>9</sup> Steele et al. 2012<sup>10</sup> found that cereal rye improved infiltration from 94 to 462 percent during the winter between corn crops.

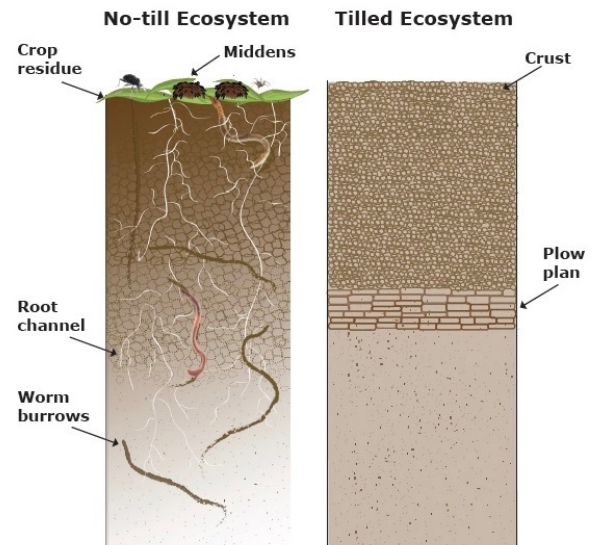
Cover crops increase infiltration rates in two ways. The first is by preventing soil sealing or crusting,

which happens when soil aggregates break down into soil particles. When the soil dries, a crust forms and seals the surface, stopping air and water from moving into the soil and forcing water to run-off. Cover crops prevent soil sealing first by shielding soil from the significant kinetic force carried by raindrops. Slowing down raindrops preserves soil aggregates and allows water to infiltrate more readily. It is a simple process with profound effects. Any surface residue, living or not, protects soil aggregates on the surface. Practices that keep residue on the soil such as no-till and mulching also greatly increase rainfall infiltration.

Cover crops do more than just protect the soil from raindrops, however. Cover crops affect infiltration rates through both physical and biological impacts on the soil. Starting from a physical perspective, infiltration occurs when water trickles into the soil. The more channels and air space that are available for water to move through, the greater the infiltration rate will be. To some degree, this depends on soil texture. Sandy soils will have higher infiltration rates than clay soils regardless of cover crops. However, cover crops can change infiltration in part by affecting how soil particles stick together, a process called aggregation. The degree to which aggregates stick together when exposed to water or force is referred to as aggregate stability. Soil aggregation and aggregate stability is highly dependent on soil biology. The glue that holds aggregates together comes from biological products such as root exudates, glomulin from fungi, earthworm casts, and bacterial byproducts. Cover crops provide roots, detritus, and habitat for soil organisms, which leads to greater aggregate stability and higher infiltration rates.

Cover crops also affect infiltration through the development of macropores. Macropores serve as channels for water and air, helping rain to soak quickly into a soil. Soil macroporosity, like aggregation, is influenced strongly by biological activity. Earthworms, in particular night crawlers, create vertical tunnels that allow rain to move quickly to deeper soil horizons. Earthworms are more abundant when there is a consistent source of residue, which cover crops provide, and undisturbed soil. Earthworms were six times more abundant in fields with a sunn hemp cover crop than on fields

with no cover crop in Kansas <sup>11</sup>. Cover crops can also form macropores if they possess deep root systems. Daikon radishes and alfalfa are perhaps better known for alleviating compaction, but their deep vertical roots also create macropores that allow for rapid and deep infiltration. The effects of deep-rooted cover crops carry into the cash crop growing season as well. Roots can penetrate deeper into less compacted soil, maintaining macropores through the growing season.



The illustration above depicts how a no-till soil with cover crops will develop numerous macropores from roots and earthworm action that allow rainwater to infiltrate quickly, versus a tilled soil where macropores are destroyed. (Illustration credit: USDA-NRCS)

Faster infiltration reduces rainfall runoff and associated erosion and nutrient losses. But infiltration is just half of the problem when it comes to runoff. Even soils with fast infiltration rates eventually become saturated, whereby further rainfall becomes runoff. Water holding capacity therefore becomes very important during heavy rainfall events.

## Soil water holding capacity and soil organic matter

Cover crops can increase soil water holding capacity through some of the same mechanisms as infiltration. Porous soil composed of stable aggregates is less dense, making more room for water. Another major reason that cover crops can improve soil water holding capacity is by building soil organic matter.



**A cover crop and no-till field on the left did a much better job of soaking up a big rain than the conventionally tilled field on the right, where water ends up ponding. (Photo credit: Russ Jackson)**

Soil organic matter plays an important role in soil fertility, tilth, plant health, water quality and water holding capacity. Organic matter consists of living or dead plants and soil organisms along stabilized remains of organisms that we call humus. It is usually estimated to be about 50 percent carbon. Soil organic matter is dynamic; the amount depends on the rate of oxidation, deposition of plant material, and microbial activity. The key characteristic behind many of organic matter's benefits is surface area. Organic matter is highly porous, so it is not very dense. Typically, this can be seen in bulk density measurements; soils with a high percentage of organic matter will have lower bulk densities. That porosity and low density allow organic matter to store water, increasing the water holding capacity of the soil. Crops benefit from soil with high water holding capacity during droughts and from reduced erosion during high rainfall events.

The surface area of soil organic matter also contributes to its ability to filter pollutants like agrochemicals, binding pollutants and allowing for microorganisms to break them down. Cover crops

have the potential to maintain and even build soil organic matter. In field research studies of varying lengths and with varying amounts of cover crop growth, legume cover crops increased soil organic matter by 10 to 31 percent while non-legumes increased it by 4 to 62 percent.<sup>12</sup> Cover crops generate organic matter by adding plant matter to the soil in the form of residue and roots. Their roots provide habitat for soil organisms that contribute to soil organic matter. They also prevent erosion, which reduces organic matter levels because it removes primarily topsoil, where the majority of organic matter is found. It is important to note that cover crops are not a silver bullet; they require skill and knowledge in order to realize their benefits. Of course, planting cover crops that fail to grow will not help build organic matter. Other ways to impact organic matter positively include reducing soil disturbance and adding manures or mulches.

## Nutrients

Modern agriculture has a nutrient problem. Gulf hypoxia and high nitrate levels in groundwater near agricultural fields are rather obvious signs that fertilizers and other chemicals are escaping from crop fields and traveling far downstream. Generally, one can improve water quality around crop fields in three ways: decreasing the amount of potential contaminants placed on fields, trapping them or breaking them down before they can leach off fields, and keeping them from running off. The last of those has been discussed in the context of erosion, infiltration and water holding capacity. Limiting runoff and erosion using cover crops and no-till means that less pollutants and fertilizers get into waterways. Reducing erosion using cover crops can significantly help water quality problems, but even in cases where erosion cannot be completely controlled, cover crops can improve water quality in other ways: by scavenging nutrients, fixing nitrogen, and supporting a biodiverse soil microbiome that breaks down excess agrichemicals.

One effective method of dealing with nutrient runoff is planting grass strips on field margins that both slow down erosive water and absorb some of the excess nutrients leaving a field, preventing them from reaching waterways. It is an effective strategy for nutrient runoff, but not for leaching. Cover crops can act in the same manner as field margin

vegetation, limiting runoff as well as leaching within a field. Living vegetation uses nutrients from the soil, but in a traditionally managed row crop field under a corn/soy rotation, there are hardly any living roots for about seven months out of the year. Those are seven months in which excess nutrients can leave the field. Cover crops provide living roots that absorb and immobilize those nutrients, keeping them from leaching.<sup>13</sup>



**Cover crops grown from fall to spring can be effective in sequestering soil nutrients, keeping them from leaching or running off fields, unlike a field with no covers where there is nothing to hold the nutrients in place. (Photo credit: R. Myers)**

An often-overlooked benefit that cover crops provide to water quality is reducing the amount of agrichemicals applied to fields. Cover crops that scavenge nutrients will release them in a form available to cash crops after termination. Additionally, legumes can fix nitrogen from the atmosphere because of the rhizobial bacteria that they host in their roots. Other nutrients are less readily provided, but cover crops can still make them available to cash crops and reduce the need for inputs. Cover crops' effects on nitrogen and other important nutrients are discussed separately below.

### **Nitrogen**

Nitrogen is the most common fertilizer applied to crops and is responsible for many water quality problems, from unsafe nitrate levels in drinking water to Gulf hypoxia. Nitrogen, unlike most other plant nutrients, is water soluble, allowing it to leave crop fields relatively easily. Cover crops can reduce the amount of nitrogen that leaves fields via runoff

and leaching. Limiting nitrogen runoff means increasing rainfall infiltration and reducing erosion, which cover crops can accomplish. Preventing nitrogen leaching requires living roots and a healthy soil microbiome that can scavenge nitrogen, which cover crops also provide. However, not all cover crops are created equal for scavenging. Grasses, small grains, and some brassicas tend to be better at scavenging nitrogen than legumes, and are generally considered to be the best cover crops for limiting nutrient losses to waterways. A review of cover crops and water quality found that grasses and brassicas decreased nitrogen leaching by 60 to 75 percent.<sup>14</sup> Nitrogen taken up by cover crops and held until cash crop planting builds the nitrogen budget available for cash crops. Correct management is key to making that nitrogen available to cash crops when they need it; grasses and small grains with high carbon to nitrogen ratios can immobilize nitrogen for some time after termination. Proper management of cover crops releases plant available nitrogen when cash crops need it.

Using nitrogen-scavenging cover crops keeps excess nitrogen out of water and can reduce the amount of fertilizer necessary by way of recycling. Some cover crops can go a step further and fix atmospheric nitrogen. Legumes like crimson clover or alfalfa add nitrogen to the soil by fixing atmospheric nitrogen with the help of bacteria associated with their roots. The amount of nitrogen fixed and available to cash crops varies by soil type, legume species, and management, but it can be significant. For example, a hairy vetch cover crop (if grown to flowering) is generally thought to provide 100 or more pounds per acre of nitrogen to the following cash crop, almost eliminating the need for additional nitrogen fertilizer for some crops.<sup>15</sup>

Different cover crops can keep nitrogen out of water in different ways. Grasses and brassicas are excellent scavengers and nitrogen recyclers, while legumes can supplement or, in some scenarios, replace nitrogen fertilizer. Mixing legumes, grasses and brassicas can maximize those benefits and help keep nitrogen out of rivers and groundwater.



**Cover crop are pictured here growing adjacent to a waterway. The cover crops help keep soil and nutrients in place, preventing them from moving off fields and into streams and lakes. (Photo credit: Edwin Remsberg)**

### **Phosphorous and micronutrients**

Phosphorous, potassium, and most micronutrients sometimes receive less attention from a water quality standpoint because of their relative insolubility in water. However, they can still leave crop fields in sediment and in water under some conditions. Phosphorous can be the major nutrient issue for water quality in certain areas; it plays a major role in Gulf hypoxia and eutrophication in the Great Lakes. Cover crops limit the sediment loss that carries phosphorous and micronutrients off fields. Increasing infiltration rates can also reduce phosphorous runoff. When fields are covered with sitting water, phosphorous that is normally bound to metals like iron can become water soluble and run off the field.

Cover crops can also scavenge excess phosphorous, potassium, and micronutrients. However, the impact of cover crops on phosphorous levels in water is not entirely clear. Some studies suggest that cover crops increase transport of soluble phosphorous through subsurface soil into waterways, canceling out benefits from reduced sediment loss. On the plus side, cover crops hold some promise in reducing the need for phosphorous application similar to nitrogen. Unlike for nitrogen however, cover crops cannot fix phosphorous or other nutrients from the atmosphere. Plants must get those nutrients from minerals within the soil, which are not always accessible or usable to plants. Cover crops make these nutrients more available to cash crops by stimulating growth of key soil organisms such as mycorrhizal fungi. These

fungi are particularly important in making phosphorous, potassium and the micronutrients available to plants. Mycorrhiza fungi increase nutrient availability by mining rock fragments for nutrients and exchanging them for carbon from plant roots. Cover crops can feed and support soil fungi and other soil life while cash crops are not growing. While cover crops alone can help soil ecosystems and decrease the need for phosphorous applications, combining cover crops with a no-till approach is helpful, since tillage destroys fungal hyphae and limits their ability to mine for nutrients.

It is worth mentioning another major source of phosphorous in some parts of the country: manure is a fairly sustainable source of nutrients for crops but applying it to fields poses challenges for water quality. There are several guidelines for applying manure to limit runoff and water contamination with phosphorous and potentially harmful bacteria such as *E. coli*. These include injecting liquid manure into the ground and avoiding applications when fields are frozen. Cover crops have the potential to reduce manure runoff buy limiting erosion and increasing infiltration, as well as keeping dangerous bacteria in the field. Some innovation might be required to reconcile current manure application technology and cover crops, so that the injection of manure does not excessively damage newly established cover crops in the fall.

### **Agrichemicals**

Agricultural fields are doused with a variety of agrichemicals every year. Glyphosate and atrazine for weeds, neonicotinoids and pyrethroids for insects, and various fungicides are all commonly sprayed or otherwise put onto crops, where they often find their way into the soil. Those chemicals can escape the fields in sediment or, if they are water-soluble, they leach or runoff. Some pesticides like neonicotinoids can be taken up by cover crops, but ultimately agrochemicals must encounter the proper microbe to keep them from leaving fields. Tilled fields without cover crops generally support a less diverse microbial and fungal community than no-till fields with cover crops. The lack of diversity decreases the chances that agrichemicals will encounter a microbe that can detoxify them or otherwise breakdown them down. Cover crops may be able to reduce the amount of pesticides applied to

fields. Some cover crops, like cereal rye, can outcompete and smother weeds, reducing the need for herbicides. Most cover crops, and in particular those allowed to flower, support a more diverse community of insects that acts as natural pest control.



**Cover crop roots can extend deep into the soil, as with the tap root that grows on down from the radish tuber pictured here. The action of roots in the soil is critical to soil health and water quality. (Photo credit: R. Myers)**

## **Summary: The power of biology**

The term “ecosystem services” is often used when justifying conservation measures and ecological research. Pollination, pest control and outdoor recreation are often cited as ecosystem services. But healthy soils might provide the most ecosystem services of them all. Biodiverse soils support healthy crops and large yields, control damaging pests, cycle and conserve nutrients, breakdown dangerous compounds, resist erosion, sequester carbon and clean water. The only way we know how to foster healthy soil ecosystems that can perform all those functions is by leaving soil undisturbed with no-till, keeping the soil covered, and maintaining a diversity of living roots in the soil year-round. Cover crops protect the soil and feed the soil ecosystem, allowing it to perform invaluable services like maintaining clean water.

Cover crops may be the cheapest solution to water quality and nutrient management problems as well. Unlike expensive precision agricultural technology, terraces, and holding ponds that are ultimately powered by fossil fuel-burning engines, cover crops do their work for free under solar power. There are seed and planting/termination costs, but these costs are minor compared to the benefits both on the farm and for overall water quality improvement efforts. Ultimately, the effectiveness of cover crops for water quality should make them part of all regional water quality management plans, and the potential savings to agencies and tax-payers should make cover crops a high priority.

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