

SOIL HEALTH & NUTRIENT MANAGEMENT

FOR IMMIGRANT FARMERS

2-DAY TRAIN-THE-TRAINER WORKSHOP



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CHAPTER

1

SOIL BASICS

BY PEYTON GINAKES AND ANNE PFEIFFER

WHAT YOU WILL LEARN

- What is soil made of?
- What does each part do?
- How does each part help plants?



What is soil?

A resource!

What have you done to help soil?



WHAT IS SOIL

In agriculture, we think of it as our BIGGEST resource. Without soil, we can't grow anything! But what else does it do, as a resource?

- Holds up people, buildings, roads, plants, and animals
- Gives plants air and water
- Hosts a LOT of microorganisms!
It is full of living things. In just ONE teaspoon (demonstrate) of soil, there can be more than 600 million organisms, many yet undiscovered - several microscopic miles of fungi, more than 10,000 individual protozoa, and 20 to 30 beneficial nematodes.



When we talk about resources, we often think of ways to conserve or protect them so that we can keep benefitting from them for a long time.

WHAT HAVE YOU DONE TO HELP SOIL?

WHAT'S IN SOIL

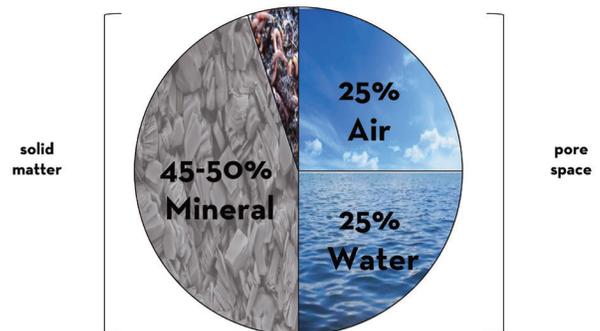
Soil has 4 major components:

- mineral particles
- organic matter
- air
- water

This means that half of soil by volume is made of solids, and half is made of pore space.

Mineral particles are individual pieces of soil, and they make up the bulk of solid soil volume - about 45-50%. Together, they make up soil texture according to their sizes. There are three size classes: sand is the biggest, silt is in the middle, and clay is the smallest.

What's in soil?

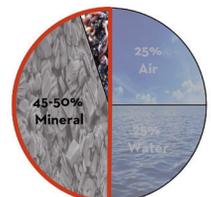


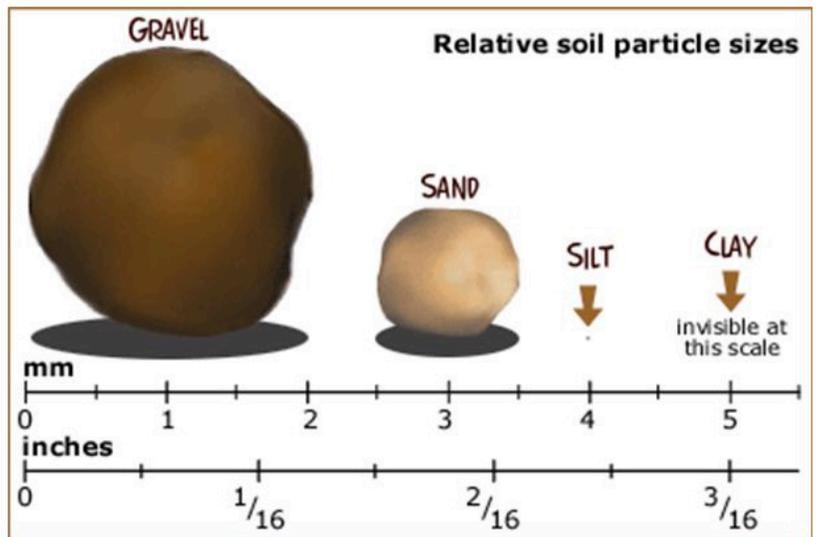
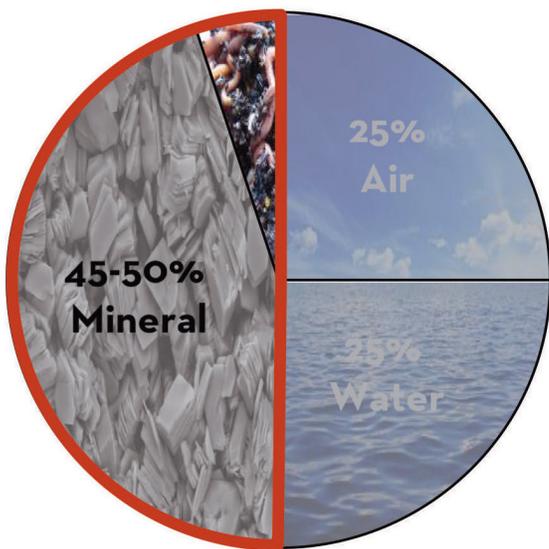
Soil is only 1/2 solid

Mineral particles are divided into 3 size classes:

- sand
- silt
- clay

The amount of each particle size determines soil "texture"





MINERAL PARTICLES

SAND

- 0.05 - 2.0 mm in size
- Sometimes visible to the eye
- Gritty when wet and dry
- Drains quickly
- Irrigation is especially important due to drainage

Since it is the largest, sand is usually visible to the naked eye. It feels gritty when it is dry and when it is wet. Since the pieces are so big, it drains rather quickly, too - we'll see more about this in a minute. What have you all noticed about sand, either here or on your farm?

SILT

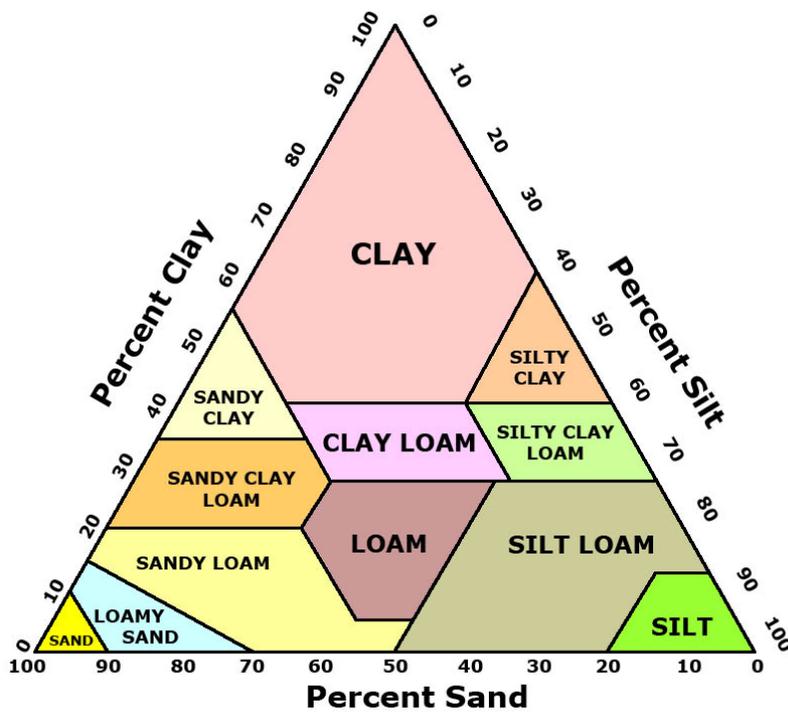
- 0.002 - 0.05 mm
- About as thick as a strand of hair!
- Feels like flour
- Don't till more than necessary, or this good soil will get washed away!

Silt is the next largest particle size. It is about as thick as a strand of hair, and the individual pieces are tough to see/often impossible. Silt usually feels very fluffy, and when it is wet, it is very smooth and floury.

CLAY

- The smallest particle size
- Less than 0.002 mm
- Invisible to the eye
- Feels sticky when wet
- Dries slowly in the spring; plan accordingly!

Clay is the smallest soil particle size. Individual pieces of clay are impossible to see, and when it is wet it is somewhat sticky. It is also very slow to drain. Have you all noticed anything about clay?



- “Loam” soil is ideal
- Soil texture cannot be changed through management!
- Soils were made over billions of years through the natural process of weathering

SOIL TEXTURE

This is a well-known image for soil scientists - we call it the “soil triangle”. It is a way to see what your final soil texture is. First you have to know the composition of your soil, though. Once you know that you find those percents on each side, then you see where they meet. (Draw out arrows on board).

So let's practice:

If you have a soil that is 35% sand, 40% silt, and 25% clay, what is your soil texture? It's a loam! A loam, or some type of loamy soil, is ideal. Unfortunately, we cannot change soil textures through management, because soil particles are made when rocks are weathered, over the course of anywhere from thousands to billions of years. Still, we can make most soil types work for farming by influencing other components.

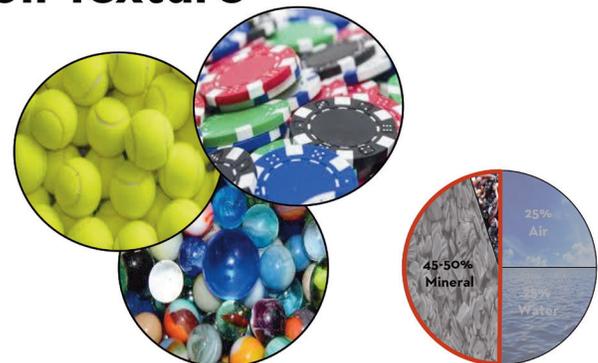
Does anyone know what their soil texture is or have an idea based on how it feels?

The main reason that we care about soil texture is because particle sizes determine pore sizes.

We are going to do a quick experiment to see why pore sizes matter. Here we have three different soil types: a sandy soil, a clayey soil, and a soil with a lot of organic matter. I'm going to pour water in each one to pretend that we just had a big rain. After a couple minutes, which soil do you think will have the most water that has passed through? Let's see.

Pore space is all the pockets between the solid parts of soil. Let's zoom in a bit and pretend that tennis balls represent sand particles. Silt has to be smaller than tennis balls then, right? Silt is like marbles. And clay is way smaller. Clay particles also tend to be flatter too, like sheets rather than roundish grains. So those are a lot like poker chips. Which soil particles have the most space between them? Sand! So

Soil Texture



let's look back at our experiment - and sure enough, water has gone through the sand most quickly! That's because it has the most space to move through, right? What about the others? Clay takes a long time to move through, there is not much space between these particles at all.

We will talk about Soil Organic Matter (SOM) more later, but we want to show you ahead of time that organic matter really increases the amount of water that soil can hold, which is awesome. SOM is the other solid part of soil, and it can make up to 5% of soil by volume. It is super important! Holding more water is just one benefit we get from SOM, and luckily, unlike soil texture, we can manage the amount of soil organic matter that is in our soils.

Let's focus on pore space for a minute. We know now that this is influenced a lot by soil texture right?

Usually, pore space is about half air, half water – and that's ideal for a lot of the things that live in soil. When this is the case, water sort of sticks to the solid particles, and air is in the bigger pores. The proportion of air and water in soil pores is a lot like a tug-of-war – when it rains, there is more water, and there is more air when it's been dry for a while.

But plants need both in the soil! Why?

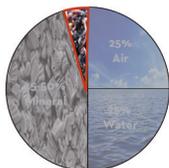
Balance is very important. If you have a clayey soil, you can use management practices that help add air channels and pockets; if you have a sandier soil, it can be managed to better hold water.

Soil Organic Matter (SOM)

organic = materials that were once alive, either recently or thousands of years ago

Mostly a source of carbon (C) and nitrogen (N), but can also provide other nutrients – very nutritious!

More on this in the next unit...

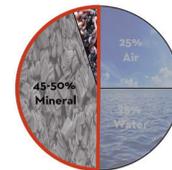


Soil is only 1/2 solid

Organic Matter can make up anywhere from 1 to 5% of soil

It's VERY important!

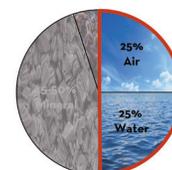
We can change how much is in soil with how we manage soil



Soil is half pore space

Soil pore space is made up of air and water:

- when it rains, it's more water than air
- when it's been dry, it's mostly air.



Soil is half pore space



Why do plants need both air and water?

SOIL ORGANIC MATTER (SOM)

We will talk about SOM a lot in our next unit, but let's just quickly touch on what soil organic matter actually is. In this case, we don't mean organic like "certified organic" – we mean it as *chemically* organic. This means that it was at some point alive, as a plant or animal – and these can have originated anywhere from a couple of weeks ago to thousands of years ago!

SOM is mainly made of carbon and nitrogen, two elements found in all living organisms. We will talk a lot about both of these elements, and focus on nitrogen management for crops in the next few units. You should also be aware that SOM has other nutrients too, just in smaller and more varying amounts. It is very nutritious for crops!

CHAPTER 1

EXPERIMENT RESOURCES

PARTICLE AND PORE SIZE DEMO

WHAT YOU NEED:

- 1 five gallon bucket or other large container
- 2 clear glasses, beakers, or other see-through glass containers of equal size
- Tennis balls
- Marbles
- Poker chips

METHODS:

1. Place tennis balls in large container
2. Place marbles in one glass/container and poker chips in another

QUESTIONS FOR CONVERSATION:

What shapes are these “particles”?

Sands and silts are rounded, grain shapes, but clays are more flat and elongated

Which of these has the most space between particles?

Sands > Silts/OM > Clays

Where are air and water in these types of soils?

Water adheres to particles, and air exists in larger pores

What happens when it rains in each soil type?

Water floods bigger and bigger pores, giving way as gravity lets out into water bodies like rivers and below-ground aquifers

Which sample will drain water more quickly?

The ones with larger pore space - in this case, sand

What role does drainage play?

We don't want water to run out too quickly, because then crops can't use it; alternatively, we don't want water to be saturated (like what happens in clays) because then crop roots “drown”

FILTRATION DEMO

WHAT YOU NEED:

- Clay soil sample
- Silt or high organic matter soil sample
- Sand soil sample
- Pop bottles (however many samples you have)
- Scissors
- 3/4 cups water

METHODS:

1. Cut the pop bottles all the way around 3 inches or so (all the same) from the top, leaving a top and bottom half
2. Remove the caps and invert the top half of the bottle into the bottom half
3. Place a cotton ball or pad into the mouth of the top half
4. Fill each top half with different soils up to 1-2 cm of the top of the surface
5. At the time of demonstration, pour the same amount of water into each soil-containing bottle top
6. Track which bottle has the most water in the bottom at a given time point (1 min, 5 min, etc.)

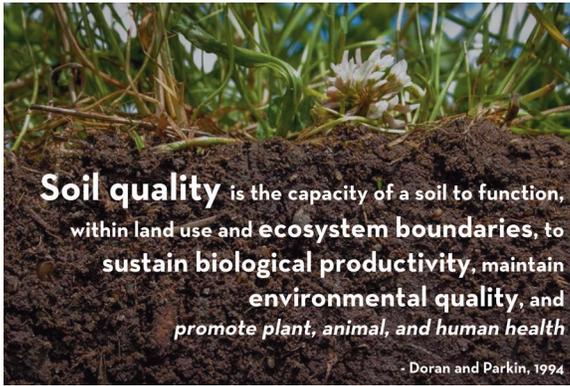
SOIL HEALTH

BY PEYTON GINAKES AND ANNE PFEIFFER

WHAT YOU WILL LEARN

- What soil health means
- How organic matter makes soil healthy
- Why we should care about soil health
- What we do that affects health of soil





Soil quality is the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health

- Doran and Parkin, 1994

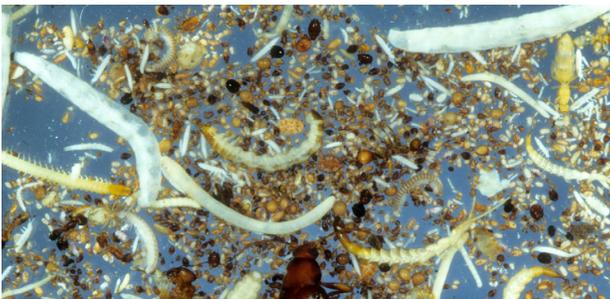
This is a big definition of soil health that's used pretty often, and here they use the word "quality" but it works for soil health too. It's long, but it basically boils down to how soil helps ecosystems function, how it keeps its ecosystem alive, how it cleans air and water, and – what's really important for farmers – how it helps plants and animals stay healthy.

Do you think of anything else when you think about soil health?

WHY SHOULD I CARE ABOUT SOIL HEALTH

Before we talk about how we can increase SOM, let's talk about why we should care about soil health.

- Why do you care about having healthy soil?
- What conditions let crops do well?
- What is your soil like?
- When are crops healthy?
- How did you manage soil where you farmed previously?
- How do you manage it here?
- Are the practices you use different?
- What did you do when you farmed before to re-energize the soil?
- Have you discovered alternative methods that are more or less suitable for re-energizing soil here?



HAVING A MORE DIVERSE SOIL FOOD WEB CAN MEAN THAT INPUTS ARE BROKEN DOWN MORE EFFICIENTLY FOR PLANTS TO USE

This image shows organisms that were found in just one tablespoon of soil! The point here is that having a more diverse soil food web can mean that inputs are broken down more efficiently for plants to use.



HAVING BETTER AGGREGATION DECREASES EROSION AND RUNOFF

What does aggregation refer to? It refers to the way and shape that soil is held together. We always want soil to stay together, especially when it's wet out, because we don't want it to wash away. We're going to do a demonstration to show how well-aggregated soils hold together even when it's wet.

Why else should we care about how soil is aggregated, or held together?

Having a diverse array of aggregate sizes also means there are lots of habitats for soil microbes!



HAVING GOOD SOIL QUALITY MEANS GOOD WATER FILTRATION!

Let's do a similar demo to talk about water quality.

What do you think the water coming out of these soils will look like? What does it mean when water is muddy versus when water is clear?

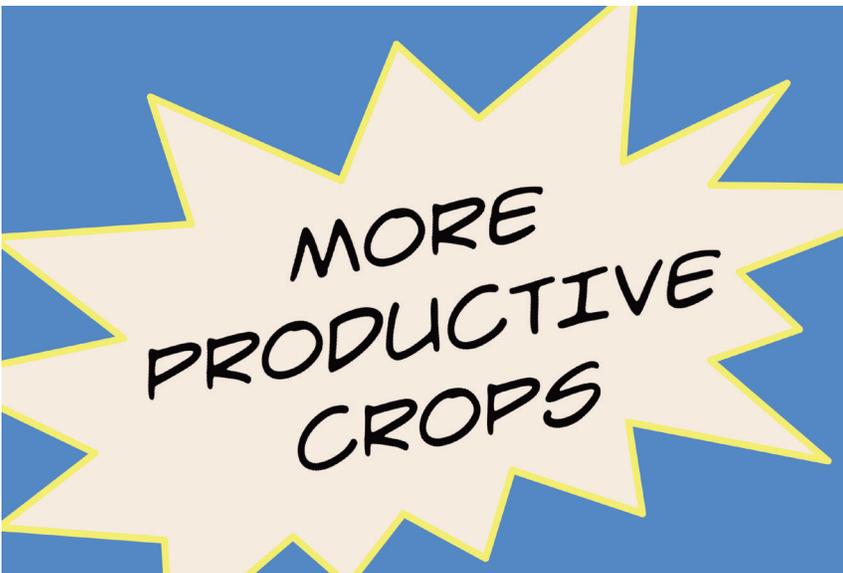
Also, in water bodies like lakes, rivers, and streams, muddiness is considered pollution because fish and other water life don't tolerate it well.



HAVING HEALTHIER SOIL CAN IMPROVE CROP RESISTANCE AGAINST PESTS AND ENVIRONMENTAL STRESSES

How many of you have gotten a cold when you haven't been getting enough sleep or eating well?

When we are under stress, sometimes our immune systems get so tired that it can't fight off what it could otherwise. Plants are the same way! When plants don't have adequate nutrition from the soil, sometimes an insect or disease attack, or heat or drought, is too much for it to handle, and the plant can't fight it off like normal. Healthy soils lead to healthy plants that can defend themselves.



Of course, all of this means that when we have healthy soils, our crops should be more productive, which is the most important part for farmers, right?

Are there other reasons we didn't talk about why for you all care about keeping the soil healthy?



THINK LIKE A ROOT

Crops need healthy roots to grow, so let's think like roots!

If you were a root,
what would you want?
How would you want your
environment?

WHAT DO YOU DO TO HELP SOIL?

Here are some big ones:

1. Crop rotation is important because if you plant the same crop in the same place every year, diseases and pests can build up in the soil. This also adds a variety of inputs, and each type of crop takes different things out of the soil too.
2. Using appropriate equipment helps soil because over-working it with aggressive machinery can degrade soil structure and aggregation.
3. Adding inputs like compost, as well as manure, add those fresh, new SOM sources for microbes to turn into plant food.
4. Finally, and what we will talk about much more in the next section, is using cover crops to improve soil health in LOTS of ways. Cover crops keep the ground covered to protect soil from erosion, their roots take up excess water and nutrients to store them for later crop use, and they're good for above-ground insects like bees. What we care about most is that when we kill cover crops and they go back into the ground, they release nutrients they accumulated and become that new SOM that microbes turn into plant food.

How Can I Help Soil Health?



CHAPTER 2 RESOURCES

- Water Quality Demo (Filtering through Soil)
- Soil Glue (NRCS)
- Slaking Fact Sheet
- Slaking Demo

Links:

UNL - CropWatch: <http://cropwatch.unl.edu/youth-soil-quality-lessons-and-videos>

3

COVER CROPS

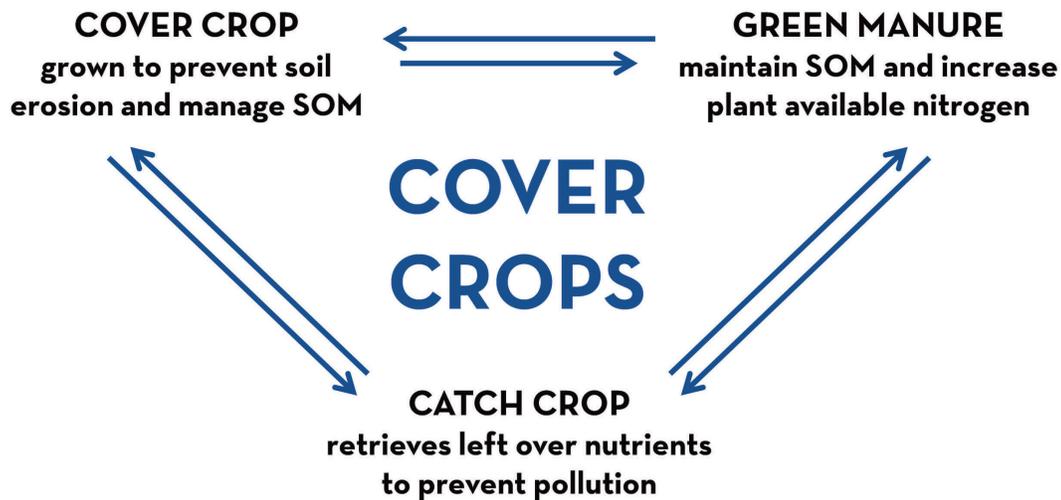
BY PEYTON GINAKES AND ANNE PFEIFFER

WHAT YOU WILL LEARN

- What a cover crop is
- Benefits and challenges of using cover crops
- How to select a cover crop
- Estimating how much N a cover crop is providing



HOW DO COVER CROPS HELP SOIL?



All these different terms exist to describe cover crops. Sometimes people talk about green manures, which just means that it adds nutrients like we do with manure (mostly N), and sometimes we talk about catch crops.

These are cover crops that tend to catch the extra nutrients before they get lost from the soil. It really doesn't matter what we call them though, because they all do lots of things, so here we'll just always say "cover crop."

HOW DO COVER CROPS HELP SOIL?

How are cover crops different from other amendments?

WHY DO WE USE COVER CROPS, HOW DO THEY HELP THE SOIL? HOW ARE THEY DIFFERENT FROM OTHER RESOURCES THAT WE CAN ADD TO SOIL?

WHAT DO YOU THINK?

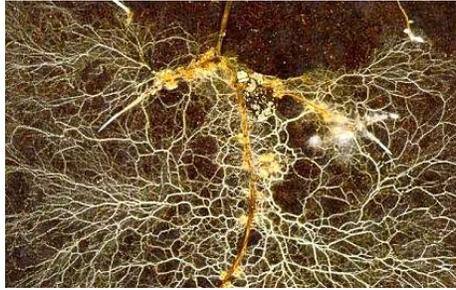
Cover crops add carbon-based organic matter to the soil, which commercial fertilizers don't typically do. Compost and manure can add organic matter, but they are often too high in phosphorus, a nutrient we'll discuss soon, when added to meet nitrogen needs. When too much phosphorus is in the soil, it can run into water bodies and kill aquatic life. Another difference between cover crops and synthetic fertilizers is that cover crops decompose slowly and their nutrient release is considered to match the timing of crop nutrient needs better than fertilizers.

HOW DO COVER CROPS HELP SOIL?



Brings in beneficial insects

Cover crops help soil in tons of ways. Of course this is aboveground, but cover crops bring in beneficial insects to the soil too. Importantly, some of those are spiders, mites, and other insects that hunt crop pests.



Increases mycorrhizae

Who has heard of mycorrhizae? Mycorrhizae are the channels that roots and fungi share, where the fungi expand plant roots to reach more resources. Cover crops expand these networks too! But we have to be careful, because tilling soil breaks up the networks.



Reduces nematodes

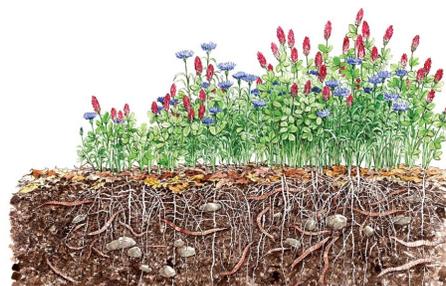
Cover crops tend to decrease the number of harmful nematodes in soil, which spread disease. Since nematodes need a constant food supply of plant roots, interrupting that with a plant root from a different plant family that it *doesn't* eat causes their populations to decline.



Decreases runoff and erosion

What happens when it rains and there is nothing between rain drops and soil?

Rain hits soil really hard and causes some of it to wash away! Having cover crops between them cushions the force of rain drops and holds the soil in place.



Increases water infiltration

Similarly, having cover crops in the soil makes lots of little channels from where roots grow that rain can follow, making the soil hold more water than it could if roots weren't there. The plants can also take up some of the water, so they're really helpful in big storms for keeping water on-site.



Scavenges excess nutrients

Do plants take up all of the nutrients we give them?

No, most plants can only use about 60-70% of the nitrogen, for instance, given to them. What happens to the rest? It can leach into water - that's a waste and a source of pollution. Some "catch crop" cover crops in particular are especially good at scavenging the leftover nutrients in soil to keep them in their biomass until the next crop needs them.

HOW DO COVER CROPS HELP SOIL?



Adds nitrogen

Who has heard of legumes? What is an example of a legume? Legumes are plants that have special relationships with specific soil bacteria called rhizobia. Rhizobia make little habitats on plant roots called nodules where they take nitrogen from the atmosphere that plants CAN'T use and turn it into plant-available nitrogen. Only legumes can do this. When rhizobia fix nitrogen, they trade it with plants for some of the plants carbon. When we put the legume plant material into the soil, it's practically free nitrogen fertilizer.



Controls weed

Some cover crops like rye are really quick-growing and competitive, so they can outgrow weeds. When some cover crops grow big enough, we can keep them in place as mulch too, to keep weeds out while the main crops are growing.



Adds organic matter

All of the plant material both above and below ground is terrific for soil because it directly becomes soil organic matter!

HAVE YOU USED COVER CROPS?

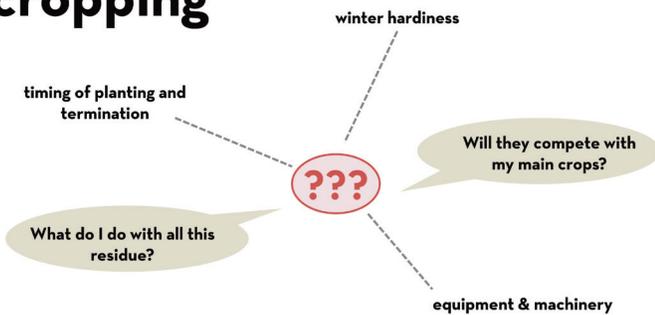
What has your experience been?

If you haven't, why not?

Or why not more?



Challenges of cover cropping



When we don't know everything about how to use cover crop, it seems really risky to use them - and there are lots of real challenges, too! For instance, not all cover crop species are strong enough to survive through the winter here, and sometimes we don't know when to plant and kill them. When it's time to kill them, you might wonder what in the world you are going to do with all of the plant material, and then what if you don't have the right equipment for the job? What if it doesn't work and they spring back to compete with my main crops?

We made a big packet of information about all kinds of cover crops we can use here with information to answer some of these questions.



1. Make a goal
2. Establish seasonal windows
3. Make plans for termination



SELECTING A COVER CROP

There are a lot of cover crop options, so when you are trying to select which ones to use, it is important to have a goal. Do you want a lot of nitrogen? Do you have lots of extra nitrogen in the soil that you need to save - do you only have a lawn mower and need something a little smaller then? Make a goal. Then look at your timeline. When are the last of your main crops in the field you want to cover crop coming out? In the cover crops you're choosing between, see what the latest planting date is. Do the same thing on the other end - what will you be planting in the spring, and will the cover crop be ready to be killed? Finally, do you have the right equipment for killing the cover crop? Some really big cover crops, like sorghum sudangrass, need a tractor to totally kill them. On the other hand, a low-lying clover can be killed with a lawn mower and rototiller.

ESTIMATING N CREDITS

One of the biggest uses of cover crops in terms of practicality is that they give us free nutrients. We are usually most interested in nitrogen, because our crops need so much of it. But how can we calculate how much nitrogen a cover crop has before we terminate it? That's the last bit of what we will talk about for this unit.

In order to see how much nitrogen is on our cover crops, we need to follow these step-by-step directions.

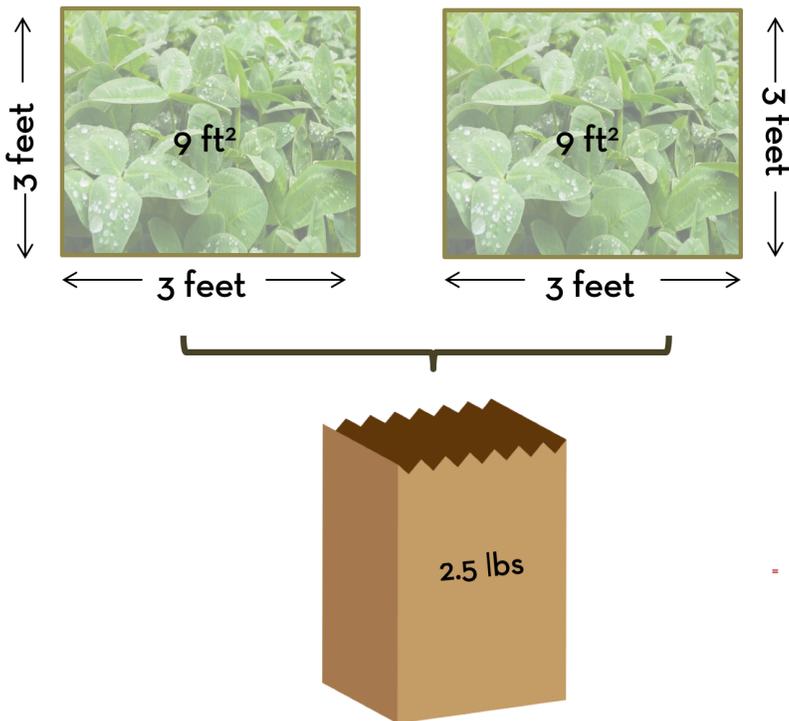
1. How much plant material is in a given area?
2. How much nitrogen is in that material?
3. How quickly will the material decompose and become available?
4. Do you need extra nitrogen?

1. HOW MUCH PLANT MATERIAL IS IN A GIVEN AREA?



1. Use a ruler or yardstick to measure out a known area in your cover cropped area
2. Clip the plants within the square at several places in your field
3. Dry the samples in the oven until they are crunchy dry

First, we want to know how much plant material is in a given space, right? So if we know how many feet are in an acre, we can sample just a foot of cover crops or so, right, and estimate from that how much is in the whole field. So you can take a ruler or meter stick to the field, make a square, and figure out how much plant matter is there. How? Lay the rulers on the ground, and collect all the plants in it from ground level and up. Put them in a paper bag and dry them at 140 F or so, until they are so dry that they are brittle or crunchy.



HOW MUCH BIOMASS PER ACRE DO I HAVE?

lb biomass/ac =

$$\frac{\text{dry sample weight (lb)}}{\text{area sampled (ft}^2\text{)}} \times \frac{43,560 \text{ ft}^2}{\text{ac}}$$

$$= \frac{2.5 \text{ lb}}{18 \text{ ft}^2} \times \frac{43,560 \text{ ft}^2}{\text{ac}} = 6,050 \text{ lb biomass}$$

Then, think about how much area you sampled from. Say you did this twice in your field, and you used yardsticks to make a square. Each square is 9ft^2 , so you have 18ft^2 , right? Then, you need to know the dry weight of the plant matter you collected. Let's pretend that these two samples together gave you 2.5 lbs. So how much biomass do you have per acre?

To get this number, you need to multiply the pounds per square foot that you have by the number of square feet in an acre. This gives us 2.5 pounds of material per 18 square feet times 43,560 square feet in an acre. What does that give us? So in one acre, we have approximately 6,050 pounds of aboveground plant biomass. That's a lot! But how much of it is nitrogen..?

2. HOW MUCH NITROGEN IS IN THAT MATERIAL?

The amount of nitrogen in a plant depends on two main things: what kind of plant it is, and how mature it is.

COVER CROP	EXAMPLES	%N
Legumes	Hairy vetch Clovers Pea Sunn hemp	4% at flowering 3% is seeds are maturing
Non-legume grasses	Rye Oat Sorghum sudangrass	3% at flowering 2% is seeds are maturing
Non-legume broad-leaves	Buckwheat Tillage radish Canola	Similar or a little less than grasses



the cover crop was flowering red clover
↓
4 %N
 $6,050 \text{ lb/ac} \times 0.04 = 242 \text{ lb N/ac}$

Plants have the most nitrogen in them right before they make seeds, so right about when they're flowering. When they make seeds, they take most of the nitrogen in their tissues, so the green parts, and shoot them into the seeds. That's why bean plants turn brown after they make beans, and why peas and beans are so high in protein - because protein is made of nitrogen! Legumes have the most nitrogen, but you can see that non-legumes have nitrogen in them too - just less.

So how much of our 6,050 lbs of biomass is actually nitrogen? Well let's say that the cover crop was red clover and it was flowering. So it should have the most nitrogen it's going to have in its lifecycle, about 4%. We just have to multiply 4% by the total amount of biomass, and then we have lbs of nitrogen per acre. What do you all get for this number? More than 200 pounds of nitrogen! But we aren't done yet...

3. HOW QUICKLY WILL THE MATERIAL DECOMPOSE AND BECOME AVAILABLE?

MICROBES HAVE TO EAT THE MATERIAL FOR IT TO BE AVAILABLE FOR PLANTS

Will you leave the cover crop:

on the surface

OR

incorporate it
belowground?



40%

will be available in year 1

$$242 \text{ lb N} \times 0.4 = 97 \text{ lb N/ac}$$



50%

will be available in year 1

$$242 \text{ lb N} \times 0.5 = 121 \text{ lb N/ac}$$

Remember, it's not all available to plants yet! Microbes have to eat it first to convert it into a form that plants can use. How quickly this will happen depends on one major thing: whether or not you till in the cover crop residue. If you leave it on the soil about 40% of it will be decomposed over the course of the year. How much is that total? Almost 100 lbs! It's a lot. If we till it in, we will get even more though, about 50%, in the first year.

Why do you think that is?

Yes, because then soil microbes have better access to it. If we till it in, how much nitrogen do we get in the first year?

121 pounds!



4. DO YOU NEED EXTRA NITROGEN?

What are you planting now?

Cabbage removes approx. 220 lb N/ac



will need $220 - 121 = 99$ more lb N
if we tilled in the clover

WHAT NOW?

Use manure, compost, or fertilizer; or, rely on accumulated soil organic N from all the organic matter you have been adding!

Finally, let's assume you will till the clover in. Is that enough nitrogen though, or do you need more for your crop? You need to know what you're planting and then have an estimate for how much nitrogen in needs in total.

I am pretending that we will plant cabbage, and I found on the internet that an acre of cabbage removes about 220 lb of nitrogen. What now? You need nearly 100

more pounds of nitrogen. You can use compost, manure, or fertilizer. But you also want to remember that if you have been building soil organic matter, some of the accumulated nitrogen will also be mineralized and made available for plants.

What questions do you have about estimating the amount of nitrogen we can give plants with cover crops?

CHAPTER 3 RESOURCES

- Albert Lea Seed
- Midwest Cover Crop Council
www.mccc.msu.edu/CCinfo/cropbycrop.html
- SARE Cover Crop Fact Sheets
- Cover Crop Comparison Chart
- Cover Crop N Contribution Calculation Worksheet

NUTRIENT MANAGEMENT

BY PEYTON GINAKES AND ANNE PFEIFFER

WHAT YOU WILL LEARN

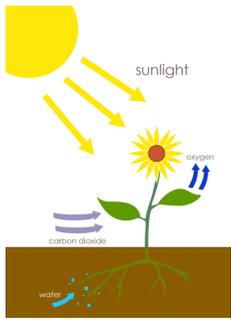
- How cover crops become plant nutrients
- Do's and don'ts of soil sampling
- Reading and using a soil test report



Let's first step back and think about what nutrients plants need, where they come from, how we provide them if they aren't already in the soil, and how they help plants grow. Then we'll talk about how soil organic matter feeds plants, and how to test soil for its nutrients.

WHERE DOES IT COME FROM?

PLANTS



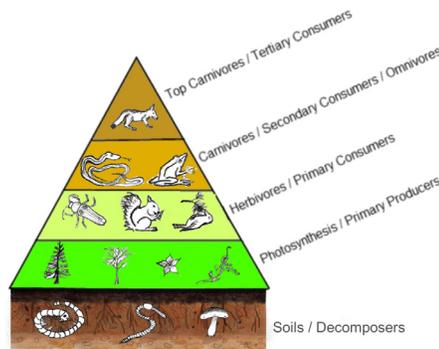
Plants grow through photosynthesis, which uses:

- sunlight
 - CO₂ from the air
 - water
- to make carbon-based plant matter.

The first big question is, “How do plants grow?” - and for all plants, the answer is that they use a process called photosynthesis. Photosynthesis is how plants take carbon dioxide (CO₂), which there’s a lot of in the air, and turns it into **organic**, or living, plant material. Plant scientists usually call this converted carbon **carbohydrates** or **photosynthates**. In order to photosynthesize, plants need sunlight, carbon dioxide, and water.

CARBON (C)

Plants make their own carbohydrates, but not all living things do. Do humans use photosynthesis? No, we eat carbon-based materials. We eat fruits and vegetables and grains, that grow using photosynthesis, and we eat food from animals who also eat plants. So carbon, even though it’s the main nutrient we consider when we think about soil organic matter, is **not** a limiting nutrient for plants. We don’t need to worry about giving plants enough carbon. We care about SOM, which is formed mostly by carbon, because of environmental reasons and because SOM holds other nutrients for plants.

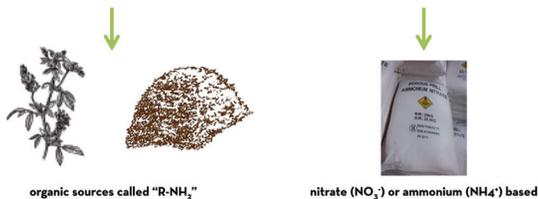


All living things (plant or animal) contain carbon, because they either photosynthesize or eat things that photosynthesize.

This process starts with plants when they fix (change) CO₂ into carbohydrates, using it to grow.

NITROGEN (N)

Organic (carbon-based) OR Inorganic (not carbon-based)



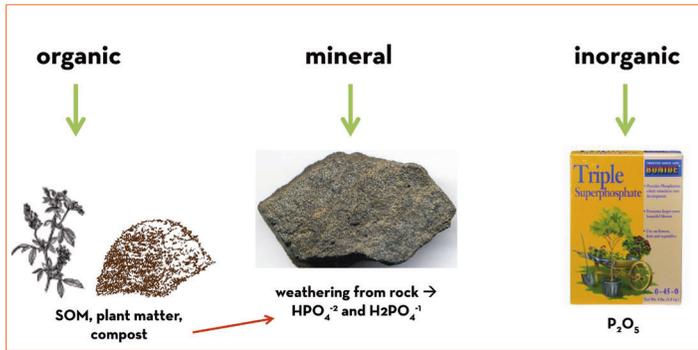
Organic N needs to be turned into nitrate (NO₃⁻) or ammonium (NH₄⁺), which is called “mineralized”, by soil microorganisms before plants can use it.

These are “made available” over time as microbes mineralize them, not all at once like fertilizers.

Next, let’s think about where nitrogen comes from. There are two main forms of nitrogen that go into soil to feed plants. The first form, organic sources of N, are what we’ve been talking about. These are sources that come from organic, or living, things, and includes cover crops, manure, and compost. The other main form of N inputs is inorganic sources. Inorganic sources are also called synthetic, because they are NOT directly made from living things. These are what we think of as commercial fertilizers: urea, anhydrous ammonia, ammonium nitrate, etc. These inorganic sources are already in forms that plants can use. Organic sources, on the other hand, are more complicated.

Organic nitrogen sources need to be “mineralized” by microbes in the soil before plants can use them. This is when microbes turn organic sources into inorganic products, like nitrate and ammonium. This doesn’t happen all at once, which is good because plants use nitrogen over time, not all at once. If it was all made available at once, a lot of it might be lost to other plants like weeds, or washed through soil into bodies of water.

PHOSPHORUS (P)



Phosphorus is another element that is essential for plants to grow, but it comes from sources that are a little different from nitrogen. Some phosphorus can be provided from organic materials - manure, in particular, provides a lot of P (so we have to be careful when we apply it because it can pollute water when there is too much!). Mineral rocks contain a lot of phosphorus also, which become part of soil when it gets weathered away. Finally, inorganic phosphorus exists through commercial fertilizers also.

Plants can only take up inorganic and soluble P.

Like N, microbes mineralize P over time from organic sources.

Sort of like how plants can only use inorganic forms of nitrogen, they can also only use inorganic forms of phosphorus that is in the soil water, which is what soluble means. Microbes mineralize P similar to how they mineralize N, from organic sources. If we were to apply manure to a field, microbes would mineralize both N and P from it.

POTASSIUM (K)



Potassium is a lot like phosphorus. It also comes from organic and mineral sources, although P and K are somewhat specific to certain rocks. Commercial K fertilizers are also available.

Plants can only take up K ions (K^+).

K^+ adheres to SOM, which keeps it from leaching and helps some of it stay available to plants.

Like N and P, plants can only use the simple, inorganic form of potassium, which is K^+ . It sticks really well to individual soil particles and also to SOM, which keep it from going into bodies of water. N and P are usually more limiting for plant growth than K.

IF PLANTS GET CARBON FROM THE AIR, WHY DO WE NEED TO BUILD SOM?

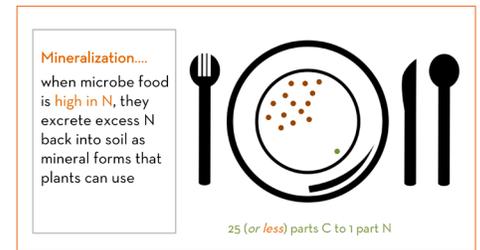
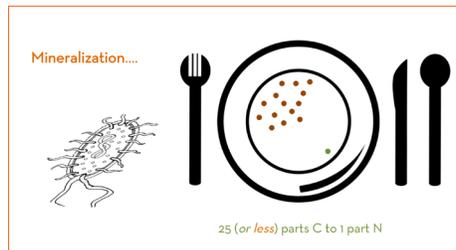
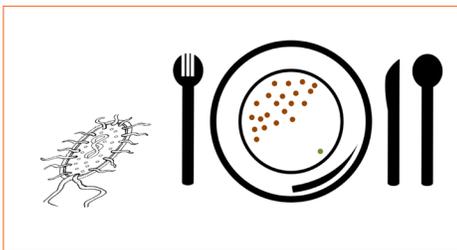
So we have focused really heavily on SOM, but if plants get their most important element, carbon, from the air, then why do we need to bother with building SOM?

What do you all think?

SOM holds other nutrients like nitrogen and phosphorus! When microbes eat SOM, they mineralize N and P, which makes them available for plants.

As mentioned it really quickly before, SOM isn't all carbon. It also includes lots of other nutrients that get stuck to it. When microbes eat pieces of SOM, they don't eat just the carbon, they eat other parts of it too, like N and P.

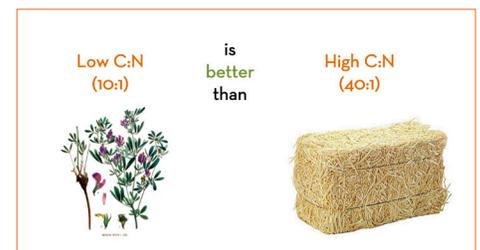
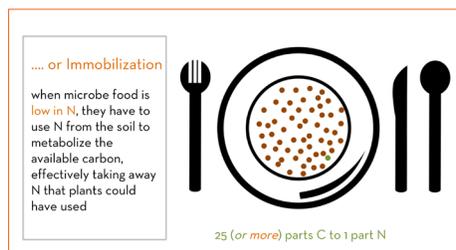
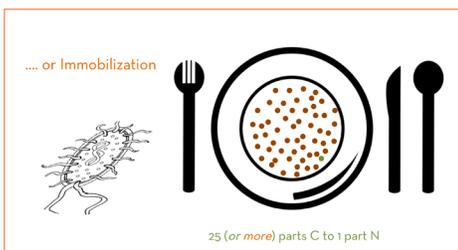
C and N in SOM



The funny thing about mineralization is that microbes need really specific amounts of elements, which is most important when it comes to nitrogen. Let's pretend that these brown dots are carbon, and the green dot is nitrogen.

For every 25 or less parts of carbon that a microbe consumes, it need also one part of nitrogen.

When they eat materials relatively high in nitrogen (which is what you might hear called "low C-to-N ratio" material), they put the extra N back into soil, but mineralized. Then plants can use it.



But sometimes, there isn't enough nitrogen. There are about 50 parts carbon here, but only one part nitrogen. But how many parts nitrogen does the microbe need if it wants to eat all the carbon? Two!

There is no extra N, so the microbes hoard what they get in their bodies rather than putting it back into the soil. That's why putting high-carbon material in soil, like straw or other woody materials, we often see a nitrogen deficiency - the microbes are hogging all the nitrogen! That's what we call immobilization.

Overall, when it comes to adding material to your soil, adding a high nitrogen material like alfalfa is much better at providing nitrogen to plants than lower N materials like straw. Remember, green things are usually higher in N than brown things, because N-based chlorophyll makes plants green!



But remember to balance! If compost is overwhelmed with carbon, then the nitrogen will become immobilized. It is also possible to add too much green material, which you'll know if your compost is too wet and smells bad. Crops only need so much nitrogen – after a certain point, they can't use anymore. Sometimes, they can even suffer from too much nitrogen. For instance, many nightshades will become big and bushy but not produce fruit, or will set fruit late.

Balance is key!

SOIL TESTING

HOW DO I SOIL SAMPLE?

- You can submit multiple samples
- Many “composites” make up one sample – for instance, take 10 soil cores and combine them in a bucket, and submit the total
- Take representative samples (only composite soil from uniform areas)
- Don't include surface plant material
- Sample as deeply as you till (usually 6-8" deep)
- The more variable your landscape (hilly, different crop rotations, different soil types, etc.), the more composites you should take!

There is a lot more to soil than meets the eye! If you are thinking about adding nutrients to soil, it's a good idea to find out what's already in the soil and to fill the gap from there. This way, you won't waste money on buying unnecessary fertilizers. So in order to know what's in your soil, it needs to be sampled from your field and sent to a testing lab. Sampling the soil is easy, but there are a few guidelines. You can collect multiple samples, which is good for if you are farming multiple locations. And each sample should be made up of about ten composites, which means cores or spade-fuls. Composites are combined to make one full sample. Make sure to get soil surface litter out of the way before soil sampling. Usually, it is a good idea to collect samples from about 6 inches deep in the soil, or as deeply as you till, because tillage incorporates nutrient sources and activates microbes.

HOW DO I READ THE REPORT?

- pH - alkaline or acidic?
- % organic matter
- soil texture
- potassium (K) and phosphorus (P)
- can measure micronutrients (Ca, Mg, Zn, B, Cu, Mn)
- can also measure nitrate
- both add to cost
- soluble salt concentrations

What will the test tell you? The soil test report should come back within two weeks (so make sure to submit your samples in time!), and it will identify your soil texture, the percent organic matter, and the acidity of your soil. It will also tell you how much P and K you have in the sample (on a per acre basis). If you choose to get extra tests done on your samples, it can also identify how much nitrogen, salts, and micronutrients your soil contains.

Here is an example of what a soil test report looks like. Again the really important parts are highlighted. How much organic matter is there? 3%, which is pretty good. It tells us the acidity, which is the “pH”. And finally it tells us the nutrients. Like we talked about, there is no nitrogen given. But it gives us values for P and K, and also recommends nutrient applications based on what we said we wanted to plant! So let’s look at the middle crop, cabbage. How much nitrogen does it need? 180 pounds per acre – that’s a lot! But we know they didn’t include soil N in that amount.

University of Minnesota Soil Testing Laboratory		SOIL TEST REPORT Farm and Field										Client Copy Department of Soil, Water, and Climate Minnesota Extension Service Agricultural Experiment Station						
FARMER DOE ROUTE 1 ANYWHERE MN 55000		Page 1 Report No. 12 Laboratory No. 18 Date Received 10/16/07 Date Reported 10/18/07																
INTERPRETATION OF SOIL TEST RESULTS																		
Soil Texture Code: H P E S A C (coarse): I R C X L sand, loamy sand, G D B C K sandy loam H L E S H L M (medium): M M I V H N loam, silt loam E D E H A F (fine): L O G I H C clay loam, D O G I H C silty clay loam, W O K S H D silty clay													Very High					
SOIL TEST RESULTS																		
Sample/Field Number	Estimated Soil Texture	Organic Matter %	Soluble Salts mhos/cm	pH	Buffer Index	Nitrate NO ₃ -N ppm	Olsen Phosphorus ppm P	Bray 1 Phosphorus ppm P	Potassium ppm K	Sulfur SO ₄ -S ppm	Zinc ppm	Iron ppm	Manganese ppm	Copper ppm	Boron ppm	Calcium ppm	Magnesium ppm	
1	Medium	3.0		7.6			6	4	75									
RECOMMENDATIONS																		
Crop and Yield Goal		Method	Lime ME/VA	N lb/A	P ₂ O ₅ lb/A	K ₂ O lb/A	S lb/A	Zn lb/A	Fe lb/A	Mn lb/A	Cu lb/A	B lb/A	Ca lb/A	Mg lb/A				
Sweet Corn 8 tons/acre		Broadcast	0	150	60	100												
Comments: 4,5,18		Row/Drill			35	40												
Cabbage		Broadcast	0	180	150	200												
Comments: 18,50,57		Row/Drill																
Tomatoes		Broadcast	0	130	150	200												
Comments: 18,50,57		Row/Drill																

County: MARTIN. For additional information, contact the soil extension specialist at: JOHN LAMB 612-625-1772

Here’s how we can figure that out on our own... We can calculate the amount of nitrogen that will be made available to plants over the course of the growing season by looking at the %SOM. Remember, before applying new nutrients, it’s a good idea to take into account what the soil already contains, and what you’ve added in terms of cover crop nutrients and other organic sources. Subtract those from what your soil test recommendations say in order to save money and not waste nutrients.

So what if you want to know how much nitrogen you have, but you don’t want to pay (and wait) for nitrate measurements?

We can do the math!

- All the soil in the top 6 inches of an acre weighs about 2,000,000 pounds.
- If we have 3% SOM, like in the report, that means we have $0.03 \times 2,000,000 = 60,000$ lb/ac of SOM
- But SOM is only about 7% nitrogen...
- So in the soil, about $60,000 \times 0.07 = 4,200$ lbs of nitrogen exist as SOM (org N)
- BUT, finally, only about 2% of this is mineralized annually...
- $4,200 \times 0.02 = 84$ lb mineral N per acre (quite a lot!)

CHAPTER 4 RESOURCES

- [Soil Sampling Guideline](http://www.extension.umn.edu)
(www.extension.umn.edu)
- Calculating Mineralizable Soil N
- Nutrient Deficiency Symptom Library for Horticultural Crops

CHAPTER 5 RESOURCES

- [N Cover Crops on the Intensive Market Farm](#)
- [Spring Rose Growers Co-op YouTube Channel](#)
- [Farm Hack](#) (website with ideas for DIY farm tools!)

REFERENCES

Sustainable Farming Association (SFA)

- <http://www.sfa-mn.org/beginning-farmer-resources/>
- <http://www.sfa-mn.org/resources/producers-marketers/>

Natural Resource Conservation Service (USDA-NRCS)

- <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>
- <http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/plantmaterials/technical/publications/?cid=stel-prdb1077238>
- <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/edu/>
- http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/assessment/?cid=nrcs142p2_053870

MN Department of Agriculture (MDA)

- <http://www.mda.state.mn.us/protecting/sustainable/mfo/beginningfarmer>

TEACHING STRATEGIES

- Think-Pair-Share: in Monday's introduction, you reflected on the questions provided about cover crops and soil health, traded reflections with your neighbor, and then shared that information with everyone
<http://www.readingrockets.org/strategies/think-pair-share>
- Brainstorming + Flip Chart: In Monday's unit on Soil Basics, you brainstormed what sorts of things might fall into soil physical, chemical, and biological properties and separated the parts into a flipchart that you can use to organize your knowledge and create your own lecture
- Case-Based Learning: at the end of Monday, we used your farming operations as examples of how and when to make cover crop decisions
<http://www.crlt.umich.edu/tstrategies/tscbt>
- Muddiest Point: at the end of Monday, you reflected on what you learned that is still most muddy, or unclear - making it easier to think more consciously about the next day and also for us to be sure to clear up
<https://cft.vanderbilt.edu/guides-sub-pages/cats/>
- Parking Lot: on Tuesday, we asked you to make individual post-its for what you had learned, what you plan to use, what we call "Aha! Moments", and what questions you still have
<http://www.competencyworks.org/how-to/creating-a-classroom-parking-lot/>
- Affinity Chart: after everyone posted their notes in the parking lot, we took it one step further to create an affinity chart - we grouped similar ideas together in order to see where everyone's ideas were similar and/or diverged, helping us see what needs clarification and how our teaching was received
https://www.mindtools.com/pages/article/newTMC_86.htm
- Peer Instruction: Tuesday morning, you taught UMN students about what you learned the day before regarding soil health and cover crops
<https://library.gwu.edu/utlc/teaching/peer-instruction>

Filtration



Soil Quality Fact Sheet

Main Concept

Soils can filter and clean water. The ability of a soil to filter water is largely dependent upon particle size and how fast water flows through soil.



Educational Goals

- Demonstrate how soils can clean water.
- Understand what properties influence the filtering of water.
- Understand how some chemicals that are spread on the ground can contaminate ground water.
- Demonstrate that sand particles do not filter chemicals from water as well as silt and clay particles do.
- Recognize that water flows through sandy soils faster than it does through clayey soils.
- Predict the outcome if colored water flows through a loamy soil (a soil that contains a mixture of sand, silt, and clay).

Materials & Preparation

- ✓ 1 Stack of bottle filters filled with sandy soil
- ✓ 1 Stack of bottle filters filled with clayey Soil
- ✓ 1 Stack of bottle filters filled with Loamy Soil (*Optional*)
- ✓ 1 Stand to secure bottle filters
- ✓ 1 Gallon of Green colored water (*Green will be used in this demonstration; food coloring recommended*)
- ✓ 1 Graduated Measuring cup
- ✓ 4-7 Clear plastic cups

Background

The relative proportions of sand, silt, clay, and organic matter influence how fast water moves through soil and how well water is cleaned. The longer it takes for water to flow through soil, the more time it has to interact with the soil and the cleaner the water becomes. Water moves slowly through clayey soils because the spaces between the individual clay particles are very small. Clay particles and organic matter have charges that attract some chemicals and keep them from moving through the soil. Water flows faster through sandy soils because of the large spaces between sand grains. The shorter time the water has to interact with the soil particles combined with the smaller surface area results in water that is not as clean as the water that flows through the clayey soil. The results of this experiment will vary over time based upon which holes the water passes through and how much water has been poured through the filters.

Explanation

If green water is poured quickly through a sandy soil, the water generally will end up green in the bottom bottle. If green water is poured very slowly through a soil high in silt and clay, it generally will take a long time to infiltrate into and through the soil, and the water will usually come out clear. If the soil is intermediate in texture, the water will come out light green.

Over time, a soil high in silt and clay will eventually become saturated with color. If green food coloring is used, light yellow water will make it through the soil first. Over time the water that makes it through the filter will gradually become more green.

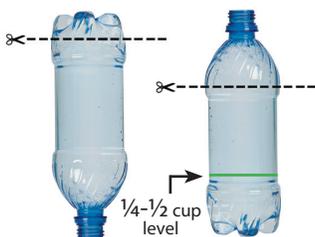
How to Make a Stack of Bottle Filters (Instructor Preparation)

Materials

- √ 5 empty plastic (16 – 20 oz) bottles
- √ Cheesecloth
- √ Rubber bands
- √ 1+1/2 cup of a type of soil (sandy, clayey, or loamy)
- √ permanent marker

STEP 1

- Remove bottoms from 4 plastic bottles.
- With 5th bottle, measure and mark where 1/4 to 1/2 cup of water reaches in the bottle. Cut off top of 5th bottle now.



STEP 2

- Cover lid end of all bottles with cheesecloth and attach with a rubber band.



STEP 3

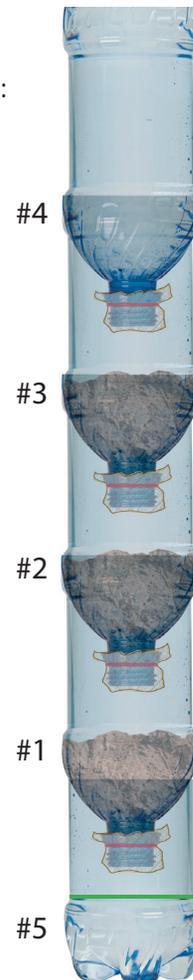
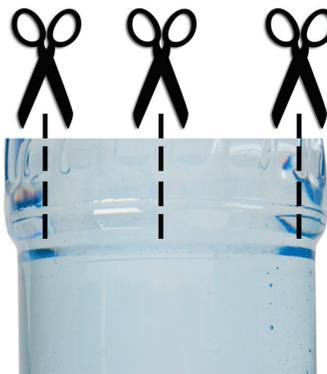
- Fill 3 of the 4 bottles without bottoms with 1/2 cup of sandy, clayey or loamy soil. Be sure to use only one type of soil in each stack of bottle filters.



STEP 4

- Mount bottles as follows (from top to bottom):
 - bottle with no bottom and no soil,
 - bottles with no bottom with soil (x3),
 - bottle with no top.

* Small vertical slits may be cut into the bottom of the bottles to improve fit.



Answers to Student Handout

1 If more filters are added to the stack, it will take longer for the water to filter to the bottom. There will be more soil to hold water against gravity as well as additional surface area to interact with the water. The soil will hold more coloring and clean the water better.

2 If fewer filters are used, it will take less time for water to filter to the bottom. There will be less soil to hold water against gravity, as well as less surface area to interact with the water. The soil will hold less coloring and the water will not be cleaned as well.

3 If water is added more slowly, it will have more time to interact with the soil and will be cleaned better.

4 If water is added more quickly, it will have less time to interact with the soil and will not be cleaned as well.

5 If water going into the soil is green and water coming out is yellow, some of the coloring was extracted from the water, but not all of it. This is called preferential absorption.

6 Answers will vary.

Further Investigations

Now that the experiment is finished, ask your students...

"What does this mean to me and why is this important?"

Answers can range from...

"I should be careful not to spill bad chemicals on the ground"

to...

"If I use chemicals I should read and follow the directions on the label."

Other topics related to soil filtration are:

- Some chemicals must be applied well before a rain because they need to have contact with plants for a while to work.
- Some chemicals must seep down into the soil to be effective, and rainfall or irrigation is required to incorporate those chemicals into the soil.
- The addition of some chemicals to soil can improve the overall health of soil, plants, and people.
- Plants grow better if proper amounts of nutrients are added.

Name: _____

Create the comparison standards:

Step 1. Fill first cup with 1 cup of colored water from gallon jug.

Step 2. Fill second cup with 1/2 cup of colored water from gallon jug and 1/2 cup of clean, clear water.

Step 3. Fill third cup with 1/4 cup of colored water from gallon jug and 3/4 cup of clean, clear water.

Step 4. Fill fourth cup with 1/8 cup of colored water from gallon jug and 7/8 cup of clean, clear water.

Note: You will use the solutions to compare the color coming from the bottle filters.

Step 5. Ask your instructor what type of soil (sand, silt, or clay) is in each stack of bottle filters.

Record the information below.

What type of soil is in each stack of bottle filters?		
Stack 1	Stack 2	Stack 3

Begin the experiment:

Pour 1/4 cup of colored water into the top of each bottle filter and record your observations below.

Observation 1 (1/4 cup of water)		
Filter 1	Filter 2	Filter 3

Try adding an additional 1/4 cup of colored water to each bottle filter. Again, record your observations.

Observation 2 (1/2 cup of water)		
Filter 1	Filter 2	Filter 3

Continue until the bottle at the base of each stack of bottle filters is filled to the line drawn on the bottle.

Record your observations.

Observation 3 (to the line)		
Filter 1	Filter 2	Filter 3

Compare solution in the base of the stack of bottle filters to that of the comparison standards you made.

Estimate amount of color removed by each stack of filters.

How much color was removed? (some, none, or all)		
Filter 1	Filter 2	Filter 3

Questions:

1. What will happen if more filters are added to the stack?

2. What will happen if fewer filters are used?

3. What will happen if water is added more slowly (1 teaspoon at a time)?

4. What will happen if water is added more quickly (1/2 cup at a time)?

5. If the water color that comes out of the soil does not match the color that went in, what might be the reason for this?

6. Was the amount of time it took for the water to filter through each stack of bottle filters the same? Why or why not?

Soil Glue

Soil Quality Fact Sheet

Main Concept

Surface soil particles are held together by various organic substances. For example, glomalin, a protein produced by fungi, acts as a “soil glue” to create stable soil aggregates. The gluing of soil particles together into aggregates helps maintain pores and channels in the soil for air and water to enter and move through it. Soil aggregates are more stable and harder to wash away than individual soil particles during rain storms.

Educational Goals

- Demonstrate that less disturbed soils contain more “soil glue” and are held together better than more disturbed soils, when soils of the same type are compared.
- Demonstrate why it is important to protect soils from disturbance.
- Provide examples of situations where soils must be disturbed along with further investigation into actions that can be taken to protect soils when they are disturbed.

Background

Soil organisms increase in abundance and in the variety of species represented when soil is not disturbed. Fungi in particular make proteins, such as glomalin, that ooze into the soil and help glue soil particles together.

When soil is heavily cultivated (tilled) or disturbed during construction, the surface layer (topsoil) is often drastically changed, buried, or removed. Change takes place when oxygen gets into the soil and provides energy for decomposers to convert dead organic matter to energy, carbon dioxide, and water. This reduces the amount of organic matter in the soil and the amount

of glue that is available to hold soil together as aggregates. Soil habitat is destroyed and live soil creatures are reduced in number and/or variety, or they are eliminated.

When the soil is not disturbed, more animals, plants, fungi, and microorganisms thrive in the soil. The amount of soil glue, such as glomalin, increases and the soil holds together better.

Explanation

Soil from the surface layer of a lawn, an orchard, or a field that has not been disturbed or tilled for a couple of years will hold together in a wire mesh basket when immersed in water. Often the soil clods will hold together so well that the water will evaporate before the soil falls apart. If any of the soil does fall through the wire mesh basket, it generally will be in the form of small soil aggregates, and the water will remain clear instead of becoming cloudy with loose soil particles.

Soil from a continuously tilled field, a construction site, or from several inches below the surface will generally fall apart (disperse) into individual soil particles when immersed in water. The loose soil will make the water cloudy, and

when it settles it will form a layer of sediment in the bottom of the jar.

In addition to level of soil disturbance, two special cases exist that affect the results of this demonstration. If the soil is held together chemically it may not fall apart during this test. Sometimes soils with a high clay content are bound together chemically.

A second exception is exhibited by the thick, dark soils of the Midwest. The mineral particles of these soils are held together by organic matter that was created decades or centuries ago. This recalcitrant organic matter is resistant to decomposition. If these soils are cultivated, the soil clods will fall apart very fast as sand-sized aggregates. The water will remain clear after the sand-sized aggregates settle to the bottom of the jar.

Examples of situations where soils must be disturbed include production of underground crops, such as potatoes and peanuts, and the construction of roads and houses.

Planting cover crops and covering disturbed soils with mulch provides protection from raindrops and food for soil glue-producing organisms.

How to Set Up the Soil Glue Demonstration *(Instructor Preparation)*

Have the following materials available for the students to prepare the demonstration.

Materials & Preparation

- ✓ 2 Wide-mouthed glass jars
- ✓ 2 Pieces of ¼-inch wire mesh about 1½ x 6 inches
- ✓ 2 Clods of soil, each about the size of an egg, from the top two inches of soil from two different areas.

Some examples of areas to sample are:

- a lawn
- a construction site
- a farmer's field that has been plowed (disturbed)
- a farmer's field that has not been disturbed for several years (no-till)
- an orchard
- a pasture
- a forest
- a worn down path



- ✓ Shape two wire mesh baskets to sit about 1½ inches below the rim of each jar
- ✓ Fill each jar with water to within ½ inch of the top
- ✓ Place soil clods from two different sources into the baskets and lower them gently into the jars
- ✓ Observe the results

Further Investigations

- ✓ Compare samples from the same soil at different depths.
- ✓ Compare samples from the same general area at the same depth to see how similarly they act.
- ✓ Compare samples from the same area before and after disturbance (before and after tilling).
- ✓ Compare moist samples to samples that have been dried. Does drying affect the results?

Answers to Student Exercise

- 1** Answers will vary. If one of the samples was taken from an area that was less disturbed than the other, there should be a visual difference in how easily the soil clods fall apart.
- 2** Answers will vary. A soil sample from a less disturbed site should stick together better.
- 3** Answers will vary. A soil that is both disturbed and contains more silt and clay will generally result in cloudy water that will take a while to clear.
- 4** The less disturbed the soil, the clearer the water, and the more stable the soil will be. Soil will have more pores and channels in it because the particles did not fall apart and fill them.
- 5** The soil that holds together the best is the soil that can resist erosion the best.

Name: _____

1. Ask your instructor about the source of the soil samples and record the information here.

What type of soil is in the wire baskets?	
Jar 1	Jar 2

2. Shape the wire mesh to create a basket that sits below the rim of the jar by about 1½ inches.

3. Fill each wide mouthed bottle with water to within ½ inch of the rim.

4. Place a clod of soil onto the wire rack and lower it gently into the water.

5. Watch the results and record your observations.

Observations after the soil was placed in water	
Jar 1	Jar 2



Crumbly soils (left) have more pores and channels than cloddy soils (right). Pores and channels allow air and water to move into the soil.



The slake test demonstrates how soil glues hold soil particles together to resist disintegration into individual particles.

Questions:

1. Did both soil samples react the same way? (Did the soil stay together or fall apart?)

2. Was the water clearer in one jar than the other?

3. If the water became cloudy, did it become clear again? How long did it take to become clear again?

4. Which soil would have more pores in it after a rain storm?

5. Which soil is more apt to resist erosion during a rain storm?



Healthy soils are held together by soil glues, or glomalin, that are produced by fungi. Soils rich in soil biota hold together, while soils devoid of soil life fall apart and form a layer of sediment in the bottom of the jar. Pictured above, the soil on the left is from a field that has been managed using no-till for several years. The soil on the right is from a conventionally-tilled field.

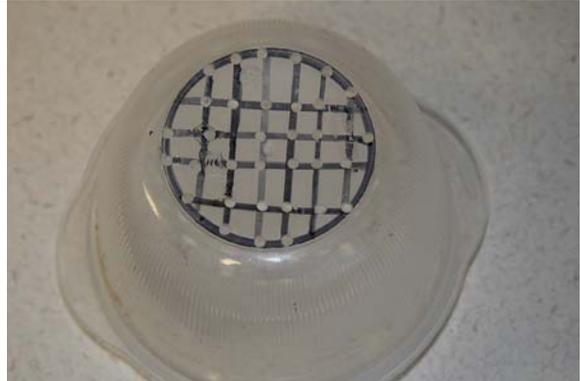
Lesson 1.1 Demonstrations

Slake Test and Miniature Rainfall Simulator

Time Allotted: 30 minutes (approximately 15 minutes for each demonstration, including discussion)

Photo of Item	Slake Test Demonstration Materials Needed and Instructions	Speaking suggestions Content help
	<p>Materials: soil aggregates</p> <ol style="list-style-type: none"> 1. Use a shovel to collect soil aggregates. Size of aggregates used in the demonstration should be approximately 2.5" in diameter. 2. Randomly collect aggregates from two locations in the same field to show contrast in management. 3. Collect aggregates from a heavily disturbed field, such as with conventional tillage. Know the tillage history of the field for discussion purposes. 4. Collect aggregates from the edge of or at a fence row of the same field where the soil is undisturbed. 5. Remove and discard chunks of soil with grass and roots from the collected soil. 6. Dry all collected soil in a microwave or allow the soil to air dry. 	
<p>Photo next page</p>	<p>Materials: jars, screen, water</p> <ol style="list-style-type: none"> 1. Acquire two glass jars approximately 10" high x 3" wide 2. Acquire screen with ¼ to ½" square slots 3. Cut two sections of screen approximately 8" long x 2.5" wide, resulting in one section of screen for each jar 	

		<p>4. Form the screen sections so they overlap by approximately 1" on two sides of the jar and dip approximately 2.5" into it</p>	
	<ol style="list-style-type: none"> 1. Fill the jars with water to within approximately 1" of the top of the jar 2. Place a soil aggregate, approximately 2.5" in diameter, on the screen; the aggregate should be suspended in the water by the screen with water completely covering it 3. Watch what happens to the aggregate 	<ol style="list-style-type: none"> 1. Does the aggregate start falling apart? 2. Is the aggregate relatively stable? 3. Is the water becoming cloudy with sediment 	
	<p>Increase individual participation in this demonstration by allowing each student to place an aggregate in their own plastic cup at their seat.</p>		

Photo	Miniature Rainfall Simulator Materials Needed and Instructions	Speaking suggestions Content help
	<p>Materials:</p> <ul style="list-style-type: none"> • 2 – plastic jars approximately 11" high x 4" wide (example: yarn jars) • 1 – permanent black marker • 1 – ruler • 1 – cordless drill • 1 – ¼" power drill bit • 2 – small plastic bowls that fit / nest into the mouth of the jar • 2 – plastic or aluminum pans to capture soil water drainage • 2 – 250 mL measuring cups • food coloring 	
	<p>Construct plastic bowls that mimic "rainfall":</p> <ol style="list-style-type: none"> 1. Make a uniform criss-cross pattern on the bottom of the plastic bowls using a permanent marker. 2. Make holes at line intersections using the drill and bit. Be careful not to press too hard on the plastic bottom since the plastic can crack. 3. Make sure both of the plastic bowls have the same number of holes on their bottom so they drip at the same rate. <p>Construct holder for soil ecosystem to receive rainfall:</p> <ol style="list-style-type: none"> 1. Drill 10 holes uniformly along the outside edge of the bottom of the yarn jars. 2. Treat each jar the same with respect to the number 	



and placement of the holes in the bottom of the jars.

Photo at left shows how the components are fitted together to set up the rainfall simulator (minus the soil; see next step for soil placement and preparation in the jars)



Place soil in the jars:

1. Fill the jars with dried, slightly crushed soil from disturbed and undisturbed treatment areas, to an approximate 3" height or until the jars are $\frac{1}{4}$ full
2. "Crushed" soil resembles the structure of a crumbly texture or well-prepared seedbed, but not pulverized; it may contain small aggregates, but larger aggregates have been broken apart
3. Make sure the jars are filled evenly
4. Tightly compact the soil that is touching the sides of the jar to prevent preferential flow between the edge of the jar and the soil
5. Do not disturb the soil in the center of the jar once it is placed there; leave it as natural as possible.
6. Treat the two jars the same with respect to soil height, compaction, etc.; the objective is to have the management show differences, not the techniques

	for setting up the demonstration	
	<ol style="list-style-type: none"> 1. Fill 250 mL measuring containers with water and mix in food coloring. 2. Place the plastic cup rainfall simulators into the mouth of the jars. 3. Hold the jars/soil/plastic cup assemblies over the plastic or aluminum trays. 	
	<p>Add water to the soil ecosystem assemblies:</p> <p>Ask participants to pour the colored water into the jars and watch for the results.</p>	
	<p>Explain that disturbance (tillage) aerates the soil and stimulates the soil bacteria to consume organic matter and soil glues; this reduces aggregation, porosity and infiltration. When the soil pores are reduced, infiltration is decreased and runoff is increased. In the confinement of the jars, ponding occurs in the disturbed sample. Limited water flows through the jar into the pan. Water infiltrates through the undisturbed sample and is caught in the pan.</p>	

Slaking

What it is: Slaking is the breakdown of large, air-dry soil aggregates (>2-5 mm) into smaller sized microaggregates (<0.25 mm) when they are suddenly immersed in water. Slaking occurs when aggregates are not strong enough to withstand internal stresses caused by rapid water uptake. Internal stresses result from differential swelling of clay particles, trapped and escaping air in soil pores, rapid release of heat during wetting, and the mechanical action of moving water.

In contrast to slaking, tests for aggregate stability measure how well soil withstands external destructive forces, such as the splashing impact of raindrops. Both poor aggregate stability and slaking result in detached soil particles that settle into pores, and cause surface sealing, reduced infiltration and plant available water, and increased runoff and erosion.

Why it is important: Slaking indicates the stability of soil aggregates, resistance to erosion and suggests how well soil can maintain its structure to provide water and air for plants and soil biota when it is rapidly wetted. Limited slaking suggests that organic matter is present in soil to help bind soil particles and microaggregates into larger, stable aggregates.

USDA NRCS Conservation Agronomist, Ray Archuleta, uses soil slaking and miniature rainfall simulator demonstrations to show how management affects soil quality on a farm located near Reidsville, North Carolina in the Piedmont MLRA. (video provided by the University of South Carolina - Earth Sciences and Resources Institute): https://www.youtube.com/watch?v=CEOyC_tGH64

Specific problems that might be caused by poor function: Slaked soil particles block soil pores, form a soil crust, reduce infiltration and water movement through soil, and increase runoff and erosion. Small aggregates produced by slaking settle together resulting in smaller pore spaces than where present with larger aggregates. Pore volume may be reduced and the ability of plants to use water stored in pore spaces may be altered.

Conservation practices that lead to slaking include:

- Conventional tillage methods that disturb soil and accelerate organic matter decomposition,
- Burning, harvesting or otherwise removing crop residues, and
- Using pesticides harmful to soil organisms that cycle organic matter and promote aggregation.

What you can do: Conservation tillage systems, such as no-till, reduce slaking by reducing soil disturbing activities that break aggregates apart and accelerate decomposition of organic matter. No-till and residue management lead to increased soil organic matter and improved aggregate stability and soil structure, particularly when cover crops or sod-based rotations provide an additional source of residue.

Conservation practices that minimize slaking include:

- Conservation Crop Rotation
- Cover Crops
- Prescribed Grazing
- Residue and Tillage management

For more information go to [Soil Management Practices](#).

Measuring slaking:

The Slake or Soil Stability Test is described in the [Soil Quality Test Kit Guide](#), Section I, Chapter 9, pp. 20 - 21. See Section II, Chapter 8, p. 72 for interpretation of results.

Herrick J.E., W.G. Whitford, A.G. de Soyza, J.W. Van Zee, K.M. Havstad, C.A. Seybold, and M. Walton. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. *Catena* 44:27-35.

Soil Quality Indicators: **Infiltration**

USDA Natural Resources Conservation Service

January 1998

What is Infiltration?

Infiltration is the process of water entering the soil. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.



Why is infiltration a concern?

Soil can be an excellent temporary storage medium for water, depending on the type and condition of the soil. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type.

If water infiltration is restricted or blocked, water does not enter the soil, and it either ponds on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants. Runoff can carry soil particles and surface applied fertilizers and pesticides off the field. These materials can end up in streams and lakes or in other places where they are not wanted.

Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or streambanks.

In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources.

Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions.

Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies.

What factors influence infiltration?

A number of factors impact soil infiltration. Some of these are:

- **Texture:** The type of soil (sandy, silty, clayey) can control the rate of infiltration. For example, a sandy surface soil normally has a higher infiltration rate than a clayey surface soil. A soil survey is a recorded map of soil types on the landscape.
- **Crust:** Soils that have many large surface connected pores have higher intake rates than soils that have few such pores. A crust on the soil surface can seal the pores and restrict the entry of water into the soil.

- **Compaction:** A compacted zone (plowpan) or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface.
- **Aggregation and Structure:** Soils that have stable strong aggregates as granular or blocky soil structure have a higher infiltration rate than soils that have weak, massive, or platelike structure. Soils that have a smaller structural size have higher infiltration rates than soils that have a larger structural size.
- **Water Content:** The content or amount of water in the soil affects the infiltration rate of the soil. The infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet. Pores and cracks are open in a dry soil, and many of them are filled in by water or swelled shut when the soil becomes wet. As they become wet, the infiltration rate slows to the rate of permeability of the most restrictive layer.
- **Frozen Surface:** A frozen soil greatly slows or completely prevents water entry.
- **Organic Matter:** An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event.
- **Pores:** Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assists the process of aggregation that enhances water infiltration.



How can infiltration be increased?

A number of management options can help increase soil infiltration:

- Decrease compaction by reducing tillage and by avoiding the use of machinery when the soils are wet. Keep the number of trips across a field to a minimum and follow the same wheel tracks for all operations, if possible.
- Decrease the formation of crusts by maintaining plant cover or by practicing residue management to reduce the impact of raindrops. Use a rotary hoe or row cultivator to shatter crust.
- Increase the amount of organic materials added to the soil to increase the stability of soil aggregates.
- Decrease or eliminate tillage operations to help maintain surface connected pores and encourage biological activity.

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<http://soils.usda.gov>

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

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soil Infiltration

Soil Health – Guides for Educators



United States Department of Agriculture
Natural Resources Conservation Service

Soil infiltration refers to the ability of the soil to allow water to move into and through the soil profile. Infiltration allows the soil to temporarily store water, making it available for use by plants and soil organisms. The infiltration rate is a measure of how fast water enters the soil, typically expressed in inches per hour. For initial in-field assessments; however, it is more practical to express the infiltration rate as the minutes needed for a soil to absorb each inch of water applied to the surface. If the rate is too slow, it can result in ponding in level areas, surface runoff, and erosion in sloping areas and can lead to flooding or inadequate moisture for crop production. Sufficient water must infiltrate the soil profile for optimum crop production. Water that infiltrates through porous soils recharges groundwater aquifers and helps to sustain the base flow in streams.

Unless properly managed, a high infiltration rate can lead to leaching of nitrate nitrogen or pesticides and loss of phosphorus from soils that have a high level of phosphorus. Management practices such as use of no-till cropping systems and use of high residue crops and cover crops can improve infiltration by increasing the soil organic matter content.

Inherent Factors Affecting Soil Infiltration

Soil texture, or the percentage of sand, silt, and clay in a soil, is the major inherent factor affecting infiltration. Water moves more quickly through the large pores in sandy soil than it does through the small pores in clayey soil, especially if the clay is compacted and has little or no structure or aggregation.

Depending on the amount and type of clay minerals, some clayey soils develop cracks from shrinkage as they become dry. The

cracks are direct conduits for water to enter the soils. Thus, clayey soils can have a high infiltration rate when dry and a slow rate when moist (cracks close). Clayey soils that do not crack have a slow infiltration rate unless they have a high content of iron oxide (red clayey soils) or they formed in volcanic ash.

Management practices that improve soil organic matter content, soil aggregation, and porosity can improve infiltration.

Infiltration Management

Management practices such as using diverse high-residue crops, maintaining residue on the soil surface, using cover crops, and managing equipment traffic to avoid compaction affect infiltration by minimizing surface crusting and compaction and increasing soil organic matter content and porosity. Unless the soil is protected by plant or residue cover, the direct impact of raindrops dislodges soil particles, resulting in runoff and erosion. The rainfall simulator in figure 1 shows that more runoff

occurs where there is less residue on the surface, increasing the risk of erosion. Dislodged soil particles fill in the surface pores, contributing to the development of a surface crust, which restricts the movement of water into the soil. Equipment use, especially on wet soils, and tillage can result in compaction. Compacted or impervious soil layers have less pore space, which restricts water movement through the soil profile.



Figure 1.—Rainfall simulator.

As soil moisture content increases, the infiltration rate decreases. Soil moisture is affected by evaporation, water use by plants, residue on surface and plant cover, irrigation, and drainage. Dry soils tend to have pores and cracks that allow water to enter faster. As a soil becomes wet, the infiltration rate slows to a steady rate based on how fast water can move through the saturated soil; the most restrictive layer, such as a compacted layer; or a dense clay layer.

Soil organic matter binds soil particles together into stable aggregates, increasing porosity and infiltration. Soils that have a high content of organic matter also provide good habitat for soil biota, such as earthworms. Soil biota increase pore space and create continuous pores that link the upper soil layer to subsurface layers.

Problems Related to Infiltration and Relationship of Infiltration to Soil Function

When rainfall is received at a rate that exceeds the infiltration rate of a soil, runoff moves downslope or ponds on the surface in level areas. Runoff on bare or sparsely vegetated soil can result in erosion. Runoff removes nutrients, chemicals, and sediment, resulting in decreased soil productivity, offsite sedimentation of bodies of water, and diminished water quality.

To determine whether runoff is likely to occur, refer to rainfall data from the nearest location

that reflects the amount and duration of rainfall in the sampled area. Compare it to the infiltration rate of the area to determine whether the rate is adequate to minimize runoff. For example, tables 1 and 2 show the likely frequency (1 to 100 years) and duration of rainfall events and the amount of rainfall received during each event at two locations in Nebraska.

To improve the soil infiltration rate:

- Avoid soil disturbance and equipment use when the soils are wet.
- Use equipment only on designated roads or between rows.
- Limit the number of times equipment is used on a field.
- Subsoil to break up compacted layers.
- Use a continuous, no-till cropping system.
- Apply solid manure or other organic material.
- Use rotations that include high-residue crops, such as corn and small grain, and perennial crops, such as grass and alfalfa.
- Plant cover crops and green manure crops.
- Farm on the contour.

Table 1.—Rainfall intensity and duration patterns for Mead, NE*

Frequency of rainfall event	Duration of rainfall event and total rainfall (in)		
	30 minutes	1 hour	2 hours
1 year	1.2	1.1	1.8
2 years	1.3	1.7	1.9
5 years	1.7	2.1	2.4
10 years	2.0	2.5	2.8
100 years	2.8	3.7	4.2

Table 2.—Rainfall intensity and duration patterns for North Platte, NE*

Frequency of rainfall event	Duration of rainfall event and total rainfall (in)		
	30 minutes	1 hour	2 hours
1 year	0.9	1.1	1.2
2 years	1.1	1.4	1.5
5 years	1.5	1.9	2.1
10 years	1.8	2.2	2.5
100 years	2.6	3.4	3.7

* D.M. Herschfield; 1961; *Rainfall Frequency Atlas of the United States*; U.S. Weather Bureau.

Restricted infiltration and ponding result in poor soil aeration. This leads to poor root function, poor plant growth, nitrogen volatilization, reduced availability of nutrients for plant use, and reduced cycling of nutrients by soil organisms.

The soil infiltration rate is most affected by conditions near the soil surface, and the rate can change drastically as a result of management.

Infiltration is rapid through large continuous pores at the soil surface, and it slows as pores become smaller. Steady-state infiltration rates typically occur when the soil is nearly saturated. These rates are given for various textural classes in table 3. They are average values and should not be generalized for all soil types.

Table 3.—Steady-state infiltration rates*
 (Soils are wet deep into the profile. Values should be used only for comparing to the infiltration rate of the second inch of water applied.)

Soil type	Steady-state infiltration rate (in/hr)
Sand	>0.8
Sandy and silty soils	0.4-0.8
Loam	0.2-0.4
Clayey soils	0.04-0.2
Sodic clayey soils	<0.04

*Hillel, 1982.

What practices are being used that affect the infiltration rate? _____

Do these practices increase or decrease the infiltration rate? Why or why not?

Measuring Infiltration

Materials needed to measure infiltration:

- ___ 3- or 6-inch-diameter aluminum ring
- ___ Rubber mallet or weight
- ___ Block of wood or plastic insertion cap
- ___ Plastic wrap
- ___ Plastic bottle marked at 107 mL (3-inch ring) or 444 mL (6-inch ring) for 1 inch of water, or graduated cylinder
- ___ Distilled water or rainwater
- ___ Stopwatch or timer

Considerations:

Select representative test locations. For comparison, select locations under different management. For example, select an area where wheeled equipment has been used and one where it has not been used. For greater accuracy, make multiple measurements (3 or more) at each representative location.

The test should not be conducted when the surface layer is unusually dry. If needed, add water and then allow the water to soak into the soil before conducting the test. The measurement can also be taken after the soil has been moistened by rain or irrigation water. The infiltration rate will vary depending on the initial moisture content; therefore, the estimated initial moisture state should be documented. Avoid areas that are not typical of the area, such as animal burrows.

Infiltration test:

1. Clear all residue from the soil surface. Drive the ring into the soil to a depth of 3 inches

using a rubber mallet or weight and a plastic insertion cap or block of wood. Take care to drive the ring downward evenly and vertically. Gently tamp down the soil inside the ring to eliminate gaps.

2. Cover the inside of the ring with plastic wrap, and drape it over the rim.
3. Pour 107 or 444 mL of distilled water or rainwater into the plastic-lined ring (fig. 2).



Figure 2.—Water is poured into plastic-lined ring.

4. Gently pull plastic wrap away. Record the time it takes for the water to infiltrate the soil. Stop timer when the soil “glistens.”
5. Repeat steps 2, 3, and 4 to determine the steady-state infiltration rate. Several measurements may be needed.
6. Record the results in table 4.
7. Remove the ring with the soil intact. This intact soil core can be used indoors for the respiration and bulk density tests.

Interpretations

In table 4, record the infiltration rate for the first and second inches of water applied and record the steady-state infiltration rate. Answer discussion questions. The infiltration rate is an

indication of the susceptibility of the soil to runoff or ponding. Compare the rate for soils in different fields, soils of different types, and soils under different management systems.

Table 4.—Infiltration data sheet

Date: May 1, 2012									
Location	Soil texture	First inch of water applied		Infiltration time for first inch (minutes)	Infiltration rate (in/hr)	Second inch of water applied		Infiltration time for second inch (minutes)	*Steady state (in/hr)
		Start time	End time			Start time	End time		
Area tracked by wheeled equipment	Silty clay loam	2:00	5:00	180	0.33	5:00	8:20	200	0.30
Area not tracked by wheeled equipment	Silty clay loam	2:00	2:01	1	N/A	2:02	4:02	120	0.5
Notes:									

*Three or more measurements (inches of water) may be needed to achieve steady-state infiltration rate.

Did the infiltration rate change from the first inch of water applied to the second inch applied? Why or why not? Would a steady-state infiltration rate be achieved if a third inch of water was applied?

Determine the rainfall patterns for your specific geographical area (tables 1 and 2 are example rainfall patterns for two locations in Nebraska and thus should not be used for all areas). How does the infiltration time compare to the expected amount of rainfall in your geographical area? Is the soil susceptible to runoff?

How do the infiltration rates compare to the steady-state infiltration rates given in table 3? Are the rates higher, lower, or similar to those for a similar soil type? Explain.

Glossary

Infiltration rate.—Measure of how fast water enters the soil. It typically is expressed as inches per hour, but it is recorded as minutes needed for each inch of water applied at the surface to move into the soil.

Restrictive layer.—Compacted layer or layer of dense clay, bedrock, or other restrictive material that limits infiltration below the surface of the soil.

Sodic soil.—Soil that has a high sodium content and thus a very low infiltration rate.

Soil aggregates.—Soil particles held together by organic matter and related substances. Well

aggregated soils have a higher infiltration rate and a lower risk of erosion.

Soil porosity.—Amount of pore space in the soil. Soils with higher porosity have more pore space and a higher infiltration rate than those with lower porosity.

Steady-state infiltration.—The condition in which the infiltration rate does not increase or decrease as more water is added. It typically occurs when the soil is nearly saturated.

	Seeding Rate (lbs/acre)			Seeds/lb	Seeding Date	Seeding Depth	Total N (lb/A/yr)	P & K Scavenger	Erosion Control	Weed Control	Quick Growth	Grazing
	Drill	Broadcast/Aerial	In Mix									
Winter Rye	50-100	120-150	25-75	18,000	Aug.-Nov.	1"	-	VG	E	E	E	E
Oats	64-96	96-128	48-64	16,000	Aug.-Sept.	1 - 2"	-	F	VG	E	E	E
Annual/Italian Ryegrass	15-20	20-30	4-5	227,000	Aug.-Sept.	¼ - ½"	-	G	VG	VG	E	E
Tillage Radish	6-8	8-10	3-4	25,000	Aug.-Sept.	¼ - ½"	-	VG	VG	E	VG	E
Purple Top Turnips	4-6	6-8	1-2	220,000	July-Aug.	¼ - ½"	-	-	F	G	G	E
Forage Rape	4-8	8-10	1-2	145,000	July-Aug.	¼ - ½"	-	VG	VG	VG	VG	E
Mustard	15-20	20-25	2-4	180,000	Aug.-Sept.	¼ - ¾"	-	G	VG	VG	VG	P
Phacelia	7-12	Not Rec.	3-5	220,000	Aug.-Sept.	¼"	-	-	VG	VG	E	-
Nitroaen Producing Cover Crop Legumes												
Hairy Vetch	25-35	30-40	15-20	16,000	Aug.-Oct.	½ - 1"	70-200	G	G	G	F	F
Winter Peas	50-100	Not Rec.	25-50	2000	Aug.-Sept.	1 - 2"	70-150	F	VG	F	VG	VG
Crimson Clover	12-25	25-30	2-5	150,000	Aug.-Sept.	¼ - ½"	55-130	G	VG	VG	G	VG
Field Peas	100-200	Not Rec.	50-100	2000	Aug.-Sept.	2 - 3"	70-150	F	VG	F	VG	E
Cowpeas	50-100	Not Rec.	20-30	3000	June-Aug.	½ - 1"	100-150	G	E	E	VG	G
Lentils	40-50	50-75	10-20	15,000	Aug.-Sept.	1 - 1½"	20-30	VG	F	G	F	E
Lupin	50-90	Not Rec.	20-40	4000	March-May	¼ - ¾"	100-200	E	G	F	VG	G
Chickling Vetch	60-70	Not Rec.	20-30	2600	March-May	1 - 1½"	80-100	F	VG	G	F	E
Sunn Hemp	15-20	Not Rec.	4-8	11,000	June-Aug.	½ - 1"	100-140	F	VG	E	E	P
Balansa Clover	5-8	6-9	2-3	500,000	July-Sept.	¼"	50-100	F	VG	E	VG	E
Common Vetch	50-60	60-75	20-40	7,000	Aug.-Sept.	½ - 1"	50-120	-	G	G	F	G
Cover Crop Mixes												
Viking NitroMax CC1 Fall Radish + Field Peas + Oats	75-125	90-150	-	-	Aug.-Sept.	½ - 1"	50-75	G	VG	E	E	E
Viking ValueMax CC2 Fall Radish + Crimson Clover + Annual Ryegrass + Rape	15-20	20-25	-	-	Aug.-Sept.	¼ - ½"	30-65	VG	VG	E	E	VG
Viking WinterMax CC3 Winter Rye + Hairy Vetch + Fall Radish	40-50	50-75	-	-	Aug.-Sept.	½ - 1"	50-75	G	VG	E	E	E
Viking BioMax CC4 Fall Radish + Annual Ryegrass	15-20	20-25	-	-	Aug.-Sept.	¼ - ½"	-	VG	VG	E	VG	E
Viking AerialMax CC5 Winter Rye + Forage Rape + Common Vetch + Lentils	60-70	75-80	-	-	Aug.-Sept.	½"	20-40	VG	E	E	VG	E
Viking SummerMax CC6 Sorghum/Sudan + Japapanese Millet + Sunn Hemp + Buckwheat + Soybeans	50-75	75-80	-	-	May-Aug.	½ - 1"	50-100	VG	E	E	E	G
Viking MultiMax CC7 Berseem Clover, Crimson Clover, Purple Top Turnips, Dwarf Essex Rape, Lentils, Annual Ryegrass	15-20	20-25	-	-	Aug.-Sept.	¼ - ½"	30-65	G	VG	VG	VG	E
Viking SpringMax CC8 Oats + Mustard	60-75	75-80	-	-	Feb.-April	¼ - ¾"	-	F	VG	VG	E	P
Plowdown Blend CC9 Mammoth Red Clover + Alfalfa + YB Sweet Clover + Alsike Clover	12-15	15-20	-	-	Feb.-May	¼ - ½"	50-100	E	G	G	P	VG

E = Excellent VG = Very Good G = Good F = Fair P = Poor

When Broadcasting/Aerial Seeding : Increase seeding rate by 25-30%
When Seeding for Forage : Increase seeding rate by 50%



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Farm Seed Comparison Chart

Type	Sowing Season	Min. Germ. Temp.	Hardiness Zone	Growth Rate	Sow Per 1,000 sq. ft.	Sow Per Acre	Seeding Depth	Nitrogen Fixation	Bees and Beneficial Insects	Compaction Control	Erosion control (Cover Crop)	Weed Suppression	Pest Management	Green Manure	Forage	Biomass (Organic Matter)
Alfalfa, Summer	Early Spring to late Summer	45°F/7°C	Frost sensitive	Fast	1/2 Lb.	15-25 Lb.	1/4-1/2"	Yes	Yes	X		X			X	X
Barley	Early Spring to Summer	38°F/3°C	7	Fast	2 Lb.	80-125 Lb.	3/4-2"				X	X		X		X
Buckwheat	Spring to Summer	50°F/10°C	Frost sensitive	Fast	2-3 Lb.	50-90 Lb.	1/2-1 1/2"		Yes			X		X		
Clover, Crimson	Anytime	45°F/7°C	7	Medium	2/3 Lb.	22-30 Lb.	1/4-1/2"	Yes	Yes		X	X		X	X	
Clover, Mammoth Red	Anytime	41°F/5°C	4	Fast	1/4 Lb.	5-15 Lb.	1/4-1/2"	Yes	Yes	X	X	X		X	X	
Clover, Medium Red	Anytime	41°F/5°C	4	Medium	1/2 Lb.	5-15 Lb.	1/4-1/2"	Yes	Yes	X	X	X		X	X	
Clover, New Zealand White	Spring to Summer	40°F/4°C	4	Slow	1/4 Lb.	5-15 Lb.	1/4-1/2"	Yes	2nd year		X	X		X	X	
Clover, Sweet	Spring to Summer	42°F/6°C	4	Medium	1/2 Lb.	10-20 Lb.	1/4-1"	Yes	2nd year	X	X	X		X	X	X
Cowpeas	Spring to Summer	58°F/14°C	Frost sensitive	Fast	2 Lb.	70-120 Lb.	1-1 1/2"	Yes						X		
Mangels	Spring to Summer	41°F/5°C	Frost sensitive	Medium	1/4 Lb.	10 Lb.	1/2-1 1/2"								X	
Manure Mix, Fall Green	Summer to Fall	45°F/7°C	See mix components	Medium	1 1/2 Lb.	50 Lb.	1/2-1 1/2"	Yes	Yes			X		X		X
Manure Mix, Spring Green	Spring to Summer	38°F/3°C	See mix components	Medium	5 Lb.	200 Lb.	1/2-1 1/2"	Yes				X		X		X
Millet, Pearl	Summer	60°F/16°C	Frost sensitive	Fast	1/4 Lb.	6-10 Lb.	1/2-1"				X	X		X		X
Mustards	Spring to Summer	40°F/4°C	7	Fast	1 Lb.	15-20 Lb.	1/4-3/4"		Yes		X	X	X	X	X	X
Oats, Common	Spring to Summer	38°F/3°C	8	Medium	4 Lb.	110-140 Lb.	1/2-1 1/2"				X	X		X		X
Oats, Hullless	Spring	38°F/3°C	8	Medium	4 Lb.	110-140 Lb.	1/2-1 1/2"				X	X		X		X
Peas, Field	Spring or Fall	41°F/5°C	7	Fast	3 Lb.	120 Lb.	1 1/2-3"	Yes				X		X		X
Radish, Oilseed	Late Summer	45°F/7°C	6	Fast	1 Lb.	10-20 Lb.	1/4-1/2"			X	X	X				
Rape, Dwarf Essex	Spring to Summer	41°F/5°C	7	Fast	1 Lb.	5-15 Lb.	1/4-3/4"						X		X	
Rye, Winter	Anytime (Fall for grain)	34°F/1°C	3	Medium	4 Lb.	60-120 Lb.	3/4-2"				X	X		X		X
Ryegrass	Anytime	40°F/4°C	6	Fast	1 Lb.	20-30 Lb.	0-1/2"				X	X		X		X
Soybeans	Spring to Summer	60°F/16°C	Frost sensitive	Fast	4 Lb.	150 Lb.	1"	Yes								
Sudangrass	Early Summer	65°F/18°C	Frost sensitive	Fast	1 Lb.	30-40 Lb.	1/2-1 1/2"			X	X	X		X	X	X
Sunflower	Spring	70°F/21°C	Frost sensitive	Medium	1,500 seeds	20,000 seeds	1/2-1"		Yes							X
Turnips	Spring or late Summer	45°F/7°C	6	Fast	1/4 Lb.	8 Lb.	1/2"								X	
Vetch, Chickling	Spring to Summer	45°F/7°C	8	Medium	2 Lb.	70 Lb.	1"	Yes			X			X		
Vetch, Hairy	Anytime	60°F/16°C	4	Slow	1 Lb.	25-40 Lb.	1/2-1 1/2"	Yes	2nd year		X			X		
Wheat, Spring	Early spring	38°F/3°C	7	Fast	4 Lb.	60-150 Lb.	1/2-1 1/2"				X	X				



Spring Green Manure Mix



Fall Green Manure Mix



Ryegrass



Oilseed Radish



Sudangrass



Mighty Mustard® Pacific Gold



Barley (Conlon)



Royal Hybrid Sunflower



Winter Rye (Common)



Spring Wheat (Glenn)



Buckwheat (Common)



Hulless Oats (Streaker)



Oats (Common)



Chickling Vetch



Hairy Vetch



Summer Alfalfa



Cowpeas (Iron & Clay)



Field Peas (Maxum)



Soybeans (Viking 2265)



Crimson Clover



Mammoth Red Clover



Sweet Clover



Medium Red Clover



New Zealand White Clover



Hybrid Pearl Millet



Dwarf Essex Rape



Purple Top Forage Turnips



Mammoth Red Mangels



Cover Crop Fact Sheet

SUSTAINABLE FARMING ASSOCIATION • SFA-MN.ORG

Prepared by Kent Solberg, SFA Livestock & Grazing Specialist

- **Cover crops are** a “tool” that can provide substantial benefits to improving soil health, productivity and farm profitability.
- **Cover crops are not** a “silver bullet” but work best in combination with diverse crop rotations, no-till, and livestock integrated into the cropping enterprise through planned grazing.
- **Complex cover crop blends**, or “biological primers,” typically consist of eight or more plant species in the mix.
- **Biological primers** have demonstrated their effectiveness in jump-starting the biological systems in many soil types and farm applications.
- **The more diverse** the complex cover crop mix, the better the response from soil microbes and the higher level of drought tolerance.
- **Biological primers** are customized to meet the needs and goals of a particular field and farm operation.
- **Previous crop history** and future cropping plans for a particular field are essential in determining a specific cover crop blend.
- **A sound crop rotation** must include representatives from each of the four major crop types: cool-season grasses, cool-season broadleaves, warm-season grasses and warm-season broadleaves (see table below for examples).
- **Drill boxes** are filled only one-third full when planting complex cover crop blends to minimize small seed from sifting to the bottom of the seed box.
- **Complex cover crop blends** may be mechanically harvested as forage; however, the greatest biological and economic impact typically occurs when grazing livestock harvest approximately one-third of the cover crop and trample the remainder to protect soil and feed microbes.
- **Aim for 120-145 percent of full seeding rate** per acre in cover crop blends.
- **Be aware of herbicide rotation restrictions** when considering cover crops.

RESOURCES

SFA soil health portal:

sfa-mn.org/soil-health-grazing

Wisconsin Extension herbicide rotation restriction brochure:

tinyurl.com/zcg9qum

YouTube: Search “Innovative No-till” and “Slake and Infiltration Test”

Burleigh County (N.D.):

bcscd.com

Cover Crop Chart:

mandan.ars.nrcs

Midwest Cover Crop Council

SmartMix Calculator™:

greencoverseed.com

EXAMPLES OF MAJOR CROP TYPES

Cool-season grasses: Oats • Barley • Wheat • Annual rye • Cereal rye • Triticale

Cool-season broadleaves: Field pea • Red clover • Hairy vetch • Common vetch • Turnip • Daikon radish

Warm-season grasses: Sorghum-sudan • Millets • Corn

Warm-season broadleaves: Soybean • Cowpea • Sunflower • Buckwheat



MCCC - Vegetable Cover Crop Decision Tool

Location Information Cash Crop Information Soil Information Attribute Information

Location Information Select a state or province

Cash Crop Warm Season Vegetables Plant Date: Harvest Date:

Drainage Information Select a drainage class Flooding No

Goal #1 Select an attribute Goal #2 Select an attribute Goal #3 Select an attribute

- Select an attribute
- Nitrogen Source
- Nitrogen Scavenger
- Soil Builder
- Plow-layer Compaction Fighter
- Topsoil Compaction Fighter
- Soil Erosion Fighter
- Wind Erosion Fighter
- Weed Fighter
- Quick Growth
- Lasting Residue
- Quick Breakdown
- Attracts Beneficials
- Nurse Crop
- Forage Value
- Seed/Grain Value

BRASSICAS AND MUSTARDS

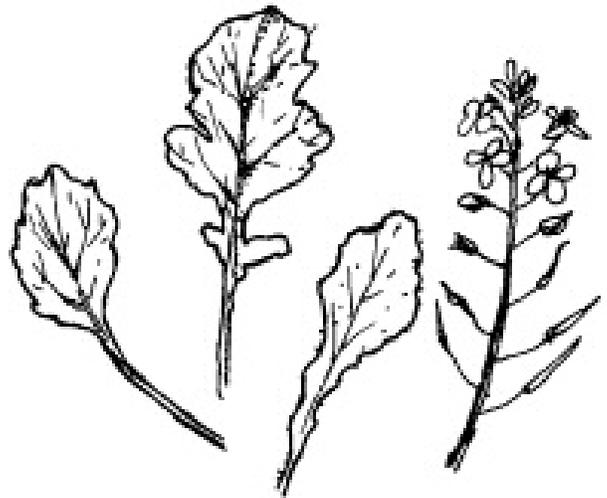
Type: Annual (usually winter or spring; summer use possible)

Roles: Prevent erosion, suppress weeds and soilborne pests, alleviate soil compaction and scavenge nutrients

Mix with: Other brassicas or mustards, small grains or crimson clover

Species: *Brassica napus*, *Brassica rapa*, *Brassica juncea*, *Brassica hirta*, *Raphanus sativus*, *Sinapsis alba*

See charts, pp. 66 to 72, for ranking and management summary.



Marianne Sarrantonio

RAPE or CANOLA (*Brassica rapa*)

Nomenclature Note: The cover crops described in this chapter all belong to the **family** BRASSICACEAE. Most but not all of the species belong to the **genus** *Brassica*. In common usage, the various species are sometimes lumped together as “brassicas” and sometimes distinguished as “brassicas” vs. “mustards.” In this book, we will use brassicas as an umbrella term for all species; mustards will be used to distinguish that subgroup, which has some unique characteristics.

Adaptation Note: This chapter addresses management of eight different cover crop species with varying degrees of winterhardiness. Some can be managed as winter or spring annuals. Others are best planted in late summer for cover crop use but will winterkill. Consult the information on management, winterhardiness and winter vs. spring use (pp. 87-88) and the examples throughout the chapter, then check with local experts for specific adaptation information for your brassica cover crop of choice.

Brassica and mustard cover crops are known for their rapid fall growth, great biomass production and nutrient scavenging ability. However, they are attracting renewed interest primarily because of their pest management characteristics. Most *Brassica* species release chemical compounds that may be toxic to soil borne pathogens and pests, such as nematodes, fungi and some weeds. The mustards usually have higher concentrations of these chemicals.

Brassicas are increasingly used as winter or rotational cover crops in vegetable and specialty crop production, such as potatoes and tree fruits. There is also growing interest in their use in row crop production, primarily for nutrient capture, nematode

trapping, and biotoxic or biofumigation activity. Some brassicas have a large taproot that can break through plow pans better than the fibrous roots of cereal cover crops or the mustards. Those brassicas that winterkill decompose very quickly and leave a seedbed that is mellow and easy to plant in.

With a number of different species to consider, you will likely find one or more that can fit your farming system. Don't expect brassicas to eliminate your pest problems, however. They are a good tool and an excellent rotation crop, but pest management results are inconsistent. More research is needed to further clarify the variables affecting the release and toxicity of the chemical compounds involved (see p. 82).

BENEFITS

Erosion control and nutrient scavenging.

Brassicas can provide greater than 80% soil coverage when used as a winter cover crop (176). Depending on location, planting date and soil fertility, they produce up to 8,000 lb. biomass/A. Because of their fast fall growth, brassicas are well-suited to capture soil nitrogen (N) remaining after crop harvest. The amount of nitrogen captured is mainly related to biomass accumulation and the amount of N available in the soil profile.

Because they immobilize less nitrogen than some cereal cover crops, much of the N taken up can become available for uptake by main crops in early to late spring (see also *Building Soil Fertility and Tillage with Cover Crops*, pp. 16-24).

Brassicas must be planted earlier than winter cereal cover crops in most regions.

Brassicas can root to depths of six feet or more, scavenging nutrients from below the rooting depth of most crops. To maximize biomass production and nutrient scavenging in the fall, brassicas must

be planted earlier than winter cereal cover crops in most regions, making them more difficult to fit into grain production rotations.

Pest management. All brassicas have been shown to release bio-toxic compounds or metabolic by-products that exhibit broad activity against bacteria, fungi, insects, nematodes, and weeds. Brassica cover crops are often mowed and incorporated to maximize their natural fumigant potential. This is because the fumigant chemicals are produced only when individual plant cells are ruptured.

Pest suppression is believed to be the result of glucosinolate degradation into biologically active sulfur containing compounds called thiocyanates (152, 320). To maximize pest suppression, incorporation should occur during vulnerable life-stages of the pest (446).

The biotoxic activity of brassica and mustard cover crops is low compared to the activity of

commercial fumigants (388). It varies depending on species, planting date, growth stage when killed, climate and tillage system. Be sure to consult local expertise for best results.

▼ **Precaution.** The use of brassicas for pest management is in its infancy. Results are inconsistent from year to year and in different geographic regions. Different species and varieties contain different amounts of bioactive chemicals. Be sure to consult local expertise and begin with small test plots on your farm.

Disease

In Washington, a SARE-funded study of brassica green manures in potato cropping systems compared winter rape (*Brassica napus*) and white mustard (*Sinapis alba*) to no green manure, with and without herbicides and fungicides. The winter rape system had a greater proportion of *Rhizoctonia*-free tubers (64%) than the white mustard (27%) and no green manure (28%) treatments in the non-fumigated plots. There was less *Verticillium* wilt incidence with winter rape incorporation (7%) than with white mustard (21%) or no green manure incorporation (22%) in non-fumigated plots (88).

In Maine, researchers have documented consistent reductions in *Rhizoctonia* (canker and black scurf) on potato following either rapeseed green manure or canola grown for grain (459, 460). They have also observed significant reductions in powdery scab (caused by *Spongospora subterranea*) and common scab (*Streptomyces scabiei*) following brassica green manures, especially an Indian mustard (*B. juncea*) green manure (458, 459).

Nematodes

In Washington state, a series of studies addressed the effect of various brassica and mustard cover crops on nematodes in potato systems (260, 266, 353, 283, 284, 285).

The Columbia root-knot nematode (*Meloidogyne chitwoodi*) is a major pest in the Pacific Northwest. It is usually treated with soil fumigants costing \$20 million in Washington alone.

Rapeseed, arugula and mustard were studied as alternatives to fumigation. The brassica cover crops are usually planted in late summer (August) or early fall and incorporated in spring before planting mustard.

Results are promising, with nematodes reduced up to 80%, but—because of the very low damage threshold—*green manures alone cannot be recommended for adequate control of Meloidogyne chitwoodi in potatoes*. The current recommended alternative to fumigation is the use of rapeseed or mustard cover crop plus the application of MOCAP. This regimen costs about the same as fumigation (2006 prices).

Several brassicas are hosts for plant parasitic nematodes and can be used as trap crops followed by an application of a synthetic nematicide. Washington State University nematologist Ekaterini Riga has been planting arugula in the end of August and incorporating it in the end of October.

Nematicides are applied two weeks after incorporation, either at a reduced rate using Telone or the full rate of Mocap and Temik. Two years of field trials have shown that arugula in combination with synthetic nematicides reduced *M. chitwoodi* to economic thresholds.

Longer crop rotations that include mustards and non-host crops are also effective for nematode management. For example, a 3-year rotation of potatoes>corn>wheat provides nearly complete control of the northern root-knot nematode (*Meloidogyne hapla*) compared to methyl bromide and other broad-spectrum nematicides.

However, because the rotation crops are less profitable than potatoes, they are less commonly used. Not until growers better appreciate the less tangible long-term cover crop benefits of soil improvement, nutrient management and pest suppression will such practices be more widely adopted.

In Wyoming, oilseed radish (*Raphanus sativus*) and yellow mustard (*Sinapsis alba*) reduced the sugar beet cyst nematode populations by 19-75%, with greater suppression related to greater amount of cover crop biomass (231).

In Maryland, rapeseed, forage radish and a mustard blend did not significantly reduce incidence of soybean cyst nematode (which is closely relat-

ed to the sugar beet cyst nematode). The same species, when grown with rye or clover, did reduce incidence of stubby root nematode (432).

Also in Maryland, in no-till corn on a sandy soil, winterkilled forage radish increased bacteria-eating nematodes, rye and rapeseed increased the proportion of fungal feeding nematodes, while nematode communities without cover crops were intermediate. The Enrichment Index, which indicates a greater abundance of opportunistic bacteria-eating nematodes, was 23% higher in soils that had brassica cover crops than the unweeded control plots.

These samples, taken in November, June (a month after spring cover crop kill), and August (under no-till corn), suggest that the cover crops, living or dead, increased bacterial activity and may have enhanced nitrogen cycling through the food web (432).

Weeds

Like most green manures, brassica cover crops suppress weeds in the fall with their rapid growth and canopy closure. In spring, brassica residues can inhibit small seeded annual weeds such as, pigweed, shepherds purse, green foxtail, kochia, hairy nightshade, puncturevine, longspine sandbur, and barnyardgrass (293), although pigweed was not inhibited by yellow mustard (178).

In most cases, early season weed suppression obtained with brassica cover crops must be supplemented with herbicides or cultivation to avoid crop yield losses from weed competition later in the season. As a component of integrated weed management, using brassica cover crops in vegetable rotations could improve weed control and reduce reliance on herbicides (39).

In Maine, the density of sixteen weed and crop species was reduced 23 to 34% following incorporation of brassica green manures, and weed establishment was delayed by 2 days, compared to a fallow treatment. However, other short-season green manure crops including oat, crimson clover and buckwheat similarly affected establishment (176).

In Maryland and Pennsylvania, forage radish is planted in late August and dies with the first hard frost (usually December). The living cover crop

and the decomposing residues suppress winter annual weeds until April and result in a mellow, weed-free seedbed into which corn can be no-tilled without any preplant herbicides. Preliminary data show summer suppression of horseweed but not lambsquarters, pigweed, or green foxtail (432).

Mustard cover crops have been extremely effective at suppressing winter weeds in tillage intensive, high value vegetable production systems in Salinas, California. Mustards work well in tillage intensive systems because they are relatively easy to incorporate into the soil prior to planting vegetables. However, the growth and biomass production by mustards in the winter is not usually as reliable as that of other cover crops such as cereal rye and legume/cereal mixtures (45).

Deep tillage. Some brassicas (forage radish, rapeseed, turnip) produce large taproots that can penetrate up to six feet to alleviate soil compaction (432). This so-called “biodrilling” is most effective when the plants are growing at a time of year when the soil is moist and easier to penetrate.

Their deep rooting also allows these crops to scavenge nutrients from deep in the soil profile. As the large tap roots decompose, they leave channels open to the surface that increase water infiltration and improve the subsequent growth and soil penetration of crop roots. Smaller roots decompose and leave channels through the plow plan and improve the soil penetration by the roots of subsequent crops (446).

Most mustards have a fibrous root system, and rooting effects are similar to small grain cover crops in that they do not root so deeply but develop a large root mass more confined to the soil surface profile.

SPECIES

Rapeseed (or Canola). Two *Brassica* species are commonly grown as rapeseed, *Brassica napus* and *Brassica rapa*. Rapeseed that has been bred to have low concentrations of both erucic acid and glucosinolates in the seed is called canola, which is a word derived from Canadian Oil.

Annual or spring type rapeseed belongs to the species *B. napus*, whereas winter-type or biennial

rapeseed cultivars belong to the species *B. rapa*. Rapeseed is used as industrial oil while canola is used for a wider range of products including cooking oils and biodiesel.

Besides their use as an oil crop, these species are also used for forage. If pest suppression is an objective, rapeseed should be used rather than canola since the breakdown products of glucosinolates are thought to be a principal mechanism for pest control with these cover crops.

Rapeseed has been shown to have biological activity against plant parasitic nematodes as well as weeds (176, 365).

Due to its rapid fall growth, rapeseed captured as much as 120 lb. of residual nitrogen per acre in Maryland (6). In Oregon, aboveground biomass accumulation reached 6,000 lb./A and N accumulation was 80 lb./A.

Some winter-type cultivars are able to withstand quite low temperatures (10° F) (352). This makes rapeseed one of the most versatile cruciferous cover crops, because it can be used either as a spring- or summer-seeded cover crop or a fall-seeded winter cover crop. Rapeseed grows 3 to 5 feet tall.

Mustard. Mustard is a name that is applied to many different botanical species, including white or yellow mustard (*Sinapis alba*, sometimes referred to as *Brassica hirta*), brown or Indian mustard (*Brassica juncea*)—sometimes erroneously referred to as canola—and black mustard (*B. nigra* (L.) (231).

The glucosinolate content of most mustards is very high compared to the true *Brassicac*s.

In the Salinas Valley, California, mustard biomass reached 8,500 lb./A. Nitrogen content on high residual N vegetable ground reached 328 lb. N/A (388, 422).

Because mustards are sensitive to freezing, winterkilling at about 25° F, they are used either as a spring/summer crop or they winter kill except in areas with little freeze danger. Brown and field mustard both can grow to 6 feet tall.

In Washington, a wheat/mustard-potato system shows promise for reducing or eliminating the soil fumigant metam sodium. White mustard and oriental mustard both suppressed potato early dying (*Verticillium dahliae*) and resulted in tuber

yields equivalent to fumigated soils, while also improving infiltration, all at a cost savings of about \$66/acre (see www.plantmanagementnet.org/pub/cm/research/2003/mustard/).

Mustards have also been shown to suppress growth of weeds (See “Weeds” p. 99 and 39, 176, 365).

Radish. The true radish or forage radish (*Raphanus sativus*) does not exist in the wild and has only been known as a cultivated species since ancient times. Cultivars developed for high forage biomass or high oilseed yield are also useful for cover crop purposes. Common types include oilseed and forage radish.

Their rapid fall growth has the potential to capture nitrogen in large amounts and from deep in the soil profile (170 lb./acre in Maryland (234). Above ground dry biomass accumulation reached 8,000 lb./acre and N accumulation reached 140 lb./acre in Michigan (304). Below ground biomass of radishes can be as high as 3,700 lb./acre.

Oilseed radish is less affected by frost than forage radish, but may be killed by heavy frost below 25° F. Radish grows about 2–3 feet tall.

Radishes have been shown to alleviate soil compaction and suppress weeds (177, 446).

Turnips. Turnips (*B. rapa* L. var. *rapa* (L.) Thell) are used for human and animal food because of their edible root. Turnip has been shown to alleviate soil compaction. While they usually do not produce as much biomass as other brassicas, they provide many macrochannels that facilitate water infiltration (359). Similar to radish, turnip is unaffected by early frost but will likely be killed by temperatures below 25° F.

In an Alabama study of 50 cultivars belonging to the genera *Brassica*, *Raphanus*, and *Sinapis*, forage and oilseed radish cultivars produced the largest amount of biomass in central and south Alabama, whereas winter-type rapeseed cultivars had the highest production in North Alabama (425).

Some brassicas are also used as vegetables (greens). Cultivated varieties of *Brassica rapa* include bok choy (*chinensis* group), mizuna (*nipposinica* group), flowering cabbage (*parachinen-*

sis group), chinese cabbage (*pekinensis* group) and turnip (*rapa* group). Varieties of *Brassica napus* include Canadian turnip, kale, rutabaga, rape, swede, swedish turnip and yellow turnip. Collard, another vegetable, is a cabbage, *B. oleracea* var. *acephala*, and *B. juncea* is consumed as mustard greens.

A grower in Maryland reported harvesting the larger roots of forage radish (cultivar DAIKON) cover crop to sell as a vegetable. In California, broccoli reduced the incidence of lettuce drop caused by *Sclerotinia* minor (175).

AGRONOMIC SYSTEMS

Brassicas must be planted earlier than small grain cover crops for maximum benefits, making it difficult to integrate them into cash grain rotations.

Broadcasting seeding (including aerial seeding) into standing crops of corn or soybean has been successful in some regions (235). See also *After 25 Years, Improvements Keep Coming*, (p. 52). Brassica growth does not normally interfere with soybean harvest, although could be a problem if soybean harvest is delayed. The shading by the crop canopy results in less cover crop biomass and especially less root growth, so this option is not recommended where the brassica cover crop is intended for compaction alleviation.

In a Maryland SARE-funded project, dairy farmers planted forage radish immediately after corn silage harvest. With a good stand of forage radish, which winterkills, corn can be planted in early spring without tillage or herbicides, resulting in considerable savings. The N released by the decomposed forage radish residues increased corn yield boost in most years. This practice is particularly useful when manure is fall-applied to corn silage fields. (For more information see SARE project report LNE03-192 http://www.sare.org/reporting/report_viewer.asp?pn=LNE03-192).

▼ **Precaution:** Brassica cover crops may be susceptible to carry-over from broadleaf herbicides applied to the previous grain crop.

Mustard Mix Manages Nematodes in Potato/Wheat System

Looking for a green manure crop to maintain soil quality in his intensive potato/wheat rotation, Dale Gies not only improved infiltration and irrigation efficiency, he also found biofumigation, a new concept in pest management.

Farming 750 irrigated acres with two sons and a son-in-law in the Columbia basin of Grant County, Wash., Gies started growing green manure crops in 1990 because he wanted to improve his soils for future generations. Since then, he has reduced his use of soil fumigants thanks to the biocidal properties of *Brassica* cover crops. In particular, Gies is most excited about results using a mixture of white or oriental mustard and arugula (*Eruca sativa*), also a brassica, to manage nematodes and potato early dying disease.

“We use the mustards to augment other good management practices,” Gies cautions. “Don’t expect a silver bullet that will solve your pest problems with one use.”

Controlling nematodes is essential to quality potato production, both for the domestic and the international market. Farmers typically manage root knot nematodes (*Meloidogyne chitwoodi*) and fungal diseases with pesticides, such as Metam sodium, a fumigant used routinely to

control early dying disease (*Verticillium dahliae*), that cost that up to \$500 per acre. Farmers are especially vulnerable to early dying disease if their rotations contain fewer than three years between potato crops.

However, with potato prices dropping, potato farmers in Washington and elsewhere started looking for ways to reduce costs. Gies contacted Andy McGuire at Washington State University Extension for help documenting the results he was seeing with brassicas. With research funding from SARE, McGuire confirmed that the mustards improved infiltration. He also showed that white mustard was as effective as metam sodium in controlling potato early dying disease.

“The findings suggest that mustard green manures may be a viable alternative to the fumigant metam sodium in some potato cropping systems,” says McGuire. “The practice can also improve water infiltration rates and provide substantial savings to farmers. Until more research is done, however, mustard cover crops should be used to *enhance*, not eliminate, chemical control of nematodes.”

Researchers have found that mustards can also suppress common root rot (*Aphanomyces euteiches*) and the northern root-knot nematode (*Meloidogyne hapla*).

Vegetable Systems. Fall-planted brassica cover crops fit well into vegetable cropping systems following early harvested crops. White mustard and brown mustard have become popular fall-planted cover crops in the potato producing regions of the Columbia Basin of eastern Washington.

Planted in mid to late August, white mustard emerges quickly and produces a large amount of biomass before succumbing to freezing temperatures. As a component of integrated weed management, using brassica cover crops in vegetable rotations could improve weed control and reduce reliance on herbicides (39).

Winter-killed forage radish leaves a nearly weed- and residue-free seedbed, excellent for early spring “no-till” seeding of crops such as carrots, lettuce, peas and sweet corn. This approach can save several tillage passes or herbicide applications for weed control in early spring and can take advantage of the early nitrogen release by the forage radish. Soils warm up faster than under heavy residue, and because no seedbed preparation or weed control is needed, the cash crop can be seeded earlier than normal.

Two types of mustard commonly used in the Columbia Basin are white mustard (*Sinapis alba*, also called *Brassica hirta* or yellow mustard), and Oriental mustard (*Brassica juncea*, also called Indian or brown mustard). Blends of the two are often planted as green manures. Fall incorporation seems to be best to control nematodes and soil-borne diseases, and Oriental mustard may be better at it than white mustard.

Gies plants a mix of mustards and NEMAT, an arugula variety developed in Italy for nematode suppression. The arugula attracts nematodes but they cannot reproduce on its roots, so nematode populations reduce, according to Washington State University researcher Ekaterini Riga.

Riga's greenhouse studies showed that arugula reduced Columbia root knot nematode (*Meloidogyne chitwoodi*) populations compared to the control or other green manure treatments. Subsequent field trial in 2005 and 2006 showed that arugula in combination with half the recommended rate of Telone (another fumigant) or full rates of Mocap and Temik reduced root knot nematode populations from 700 nematodes per gram of soil to zero. The combination also improved potato yield and tuber quality and it is still affordable by the growers.

"Arugula acts both as a green manure and a nematode trap crop," says Riga.

"It contains chemicals with high biocidal activity that mimic synthetic fumigants. Since nematodes are attracted to the roots of Arugula, it can be managed as a trap crop."

What causes brassicas to have biocidal properties? Researchers are keying in on the presence of glucosinolates in mustards. When the crop is incorporated into the soil, the breakdown of glucosinolates produces other chemicals that act against pests. Those secondary chemicals behave like the active chemical in commercial fumigants like metam sodium.

More research is needed to better determine site- and species-specific brassica cover crop effects on pests. It seems to be working for Dale Gies, however, "whose short season fresh market potato system probably functions differently than processing potatoes" according to WSU's Andy McGuire. To stay updated on cover crop work in Washington State, see www.grant-adams.wsu.edu/agriculture/covercrops/green_manures/.

For Gies, however, "Tying the whole system together makes it work economically, *and* it improves the soil."

—Andy Clark

MANAGEMENT

Establishment

Most *Brassica* species grow best on well drained soils with a pH range of 5.5–8.5. Brassicas do not grow well on poorly drained soils, especially during establishment. Winter cover crops should be established as early as possible. A good rule of thumb is to establish brassicas about 4 weeks prior to the average date of the first 28° F freeze. The minimum soil temperature for planting is 45° F; the maximum is 85° F.

Winter hardiness

Some brassicas and most mustards may winterkill, depending on climate and species. Forage radish normally winter kills when air temperatures drop below 23° F for several nights in a row. Winter hardiness is higher for most brassicas if plants reach a rosette stage between six to eight leaves before the first killing frost.

Some winter-type cultivars of rapeseed are able to withstand quite low temperatures (10° F) (352).

Late planting will likely result in stand failure and will certainly reduce biomass production and nutrient scavenging. Planting too early, however, may increase winterkill in northern zones (166).

In Washington (Zone 6), canola and rapeseed usually overwinter, mustards do not. Recent work with arugula (*Eruca sativa*) shows that it does overwinter and may provide similar benefits as the mustards (430).

In Michigan, mustards are planted in mid-August, and winterkill with the first hard frost, usually in October. When possible, plant another winter cover crop such as rye or leave strips of untilled brassica cover crop rather than leave the soil without growing cover over the winter (391).

In Maine, all brassica and mustards used as cover crops winterkill (166).

Winter vs. spring annual use

Brassica and mustard cover crops can be planted in spring or fall. Some species can be managed to winterkill, leaving a mellow seedbed requiring little or no seedbed preparation. For the maximum benefits offered by brassicas as cover crops, fall-planting is usually preferable because planting conditions (soil temperature and moisture) are more reliable and the cover crops produce more dry matter.

In Maryland, rapeseed and forage radish were more successful as winter- rather than spring-annual cover crops. The early spring planted brassicas achieved about half the quantities of biomass and did not root as deeply, before bolting in spring (432).

In Michigan, mustards can be planted in spring following corn or potatoes or in fall into wheat residue or after snap beans. Fall seedings need about 900 growing-degree-days to produce acceptable biomass, which is usually incorporated at first frost (usually October). Spring seeding is less reliable due to cool soil temperatures, and its use is limited mostly to late-planted vegetable crops (391).

In Maine, brassicas are either planted in late summer after the cash crop and winterkill, or they are spring-seeded for a summer cover crop (166).

Rapeseed planted in late spring to summer has been used with some success in the mid-Atlantic

region to produce high biomass for incorporation to biofumigate soil for nematodes and diseases prior to planting strawberries and fruit trees.

Mixtures. Mix with small grains (oats, rye), other brassicas or legumes (e.g. clover). Brassicas are very competitive and can overwhelm the other species in the mixture. The seeding rate must be adjusted so ensure adequate growth of the companion species. Consult local expertise and start with small plots or experiment with several seeding rates.

Washington farmers use mixtures of white and brown mustard, usually with a greater proportion of brown mustard.

In Maryland and Pennsylvania, farmers and researchers seed the small grain and forage radish in separate drill rows rather than mixing the seed. This is done by taping closed alternate holes in the two seeding boxes of a grain drill with both small seed and large seed boxes. Two rows of oats between each row of forage radish has also proven successful (432). Rye (sown at 48 lb./A) can be grown successfully as a mixture with winter-killing forage radish (13 lb./A).

Killing

Brassica cover crops that do not winterkill can be terminated in spring by spraying with an appropriate herbicide, mowing, and/or incorporating above-ground biomass by tillage before the cover crop has reached full flower. Rolling may also be used to kill these covers if they are in flower.

Rapeseed has proved difficult to kill with glyphosate, requiring a higher than normal rate of application—at least 1 quart/acre of glyphosate—and possibly multiple applications. Radish, mustard, and turnip can be killed using a full rate of paraquat, multiple applications of glyphosate, or glyphosate plus 1pt/acre 2,4-D.

In Alabama and Georgia, brassica cover crops were reportedly harder to chemically kill than winter cereals. Timely management and multiple herbicide applications may be necessary for successful termination. If not completely killed, rapeseed volunteers can be a problem in the subsequent crop. Always check herbicide rotation restrictions before applying.

Another no-till method for terminating mature brassicas is flail mowing. Be sure to evenly distribute residue to facilitate planting operations and reduce allelopathic risk for cash crop. As mentioned above, many producers incorporate brassica residues using conventional tillage methods to enhance soil biotoxic activity especially in plasticulture systems.

Brassica pest suppression may be more effective if the cover crop is incorporated.

Seed and Planting

Because *Brassica* spp. seed may be scarce, it is best to call seed suppliers a few months prior to planting to check on availability. *Brassica* seeds in general are relatively small; a small volume of seed goes a long way.

- Rapeseed (Canola). Drill 5-10 lb./A no deeper than $\frac{3}{4}$ in. or broadcast 8-14 lb./A.
- Mustard. Drill 5-12 lb./A $\frac{1}{4}$ - $\frac{3}{4}$ in. deep or broadcast 10-15 lb./A.
- Radish. Drill 8 to 12 lb./A. $\frac{1}{4}$ - $\frac{1}{2}$ in. deep, or broadcast 12-20 lb./A. Plant in late summer or early fall after the daytime average temperature is below 80° F
- Turnip. Drill 4-7 lb./A about $\frac{1}{2}$ in. deep or broadcast 10-12 lb./A. Plant in the fall after the daytime average temperature is below 80° F

Nutrient Management

Brassicas and mustards need adequate nitrogen and sulfur fertility. Brassica sulfur (S) nutrition needs and S uptake capacity exceed those of many other plant species, because S is required for oil and glucosinolate production. A 7:1 N/S ratio in soils is optimum for growing rape, while N/S ratios ranging from 4:1 to 8:1 work well for brassica species in general.

Ensuring sufficient N supply to brassicas during establishment will enhance their N uptake and early growth. Some brassicas, notably rape, can scavenge P by making insoluble P more available to them via the excretion of organic acids in their root zone (168).

Brassicas decompose quickly. Decomposition and nutrient turnover from roots (C:N ratios 20-30) is expected to be slower than that from shoots (C:N ratios 10-20), but overall faster than

that of winter rye. A winter-killed radish cover crop releases plant available nitrogen especially early in spring, so it should be followed by an early planted nitrogen demanding crop to avoid leaching losses (432).

COMPARATIVE NOTES

Canola is more prone to insect problems than mustards, probably because of its lower concentration of glucosinolates.

In the Salinas Valley, which has much milder summer and winter temperatures than the Central Valley of California, brassica cover crops are generally less tolerant of suboptimal conditions (i.e. abnormally low winter temperatures, low soil nitrogen, and waterlogging), and hence are more likely to produce a nonuniform stand than other common cover crops (45).

▼ **Precautions.** The use of brassicas for pest management is in its infancy. Results are inconsistent from year to year and in different geographic regions. Be sure to consult local expertise and begin with small test plots on your farm.

Bio-toxic activity can stunt cash crop growth, thus avoid direct planting into just-killed green residue.

Brassica cover crops should NOT be planted in rotation with other brassica crops such as cabbage, broccoli, and radish because the latter are susceptible to similar diseases. Also, scattered volunteer brassica may appear in subsequent crops. Controlling brassica cover crop volunteers that come up in brassica cash crops would be challenging if not impossible.

Black mustard (*Brassica nigra*) is hardseeded and could cause weed problems in subsequent crops (39).

Rapeseed contains erucic acid and glucosinolates, naturally occurring internal toxicants. These compounds are anti-nutritional and are a concern when feeding to livestock. Human consumption of brassicas has been linked to reducing incidence of cancer. All canola cultivars have been improved through plant breeding to contain less than 2% erucic acid.

Clark, Andy (ed.). 2007. Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network, Beltsville, MD.

Winter rape is a host for root lesion nematode. In a SARE funded study in Washington, root lesion nematode populations were 3.8 times higher in the winter rape treatment than in the white mustard and no green manure treatments after green manure incorporation in unfumigated plots. However, populations in the unfumigated winter rape treatment were below the economic threshold both years of the study. For more information,

go to www.sare.org/projects/ and search for SW95-021. See also SW02-037).

Rapeseed may provide overwintering sites for harlequin bug in Maryland (432). 🌱

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BUCKWHEAT

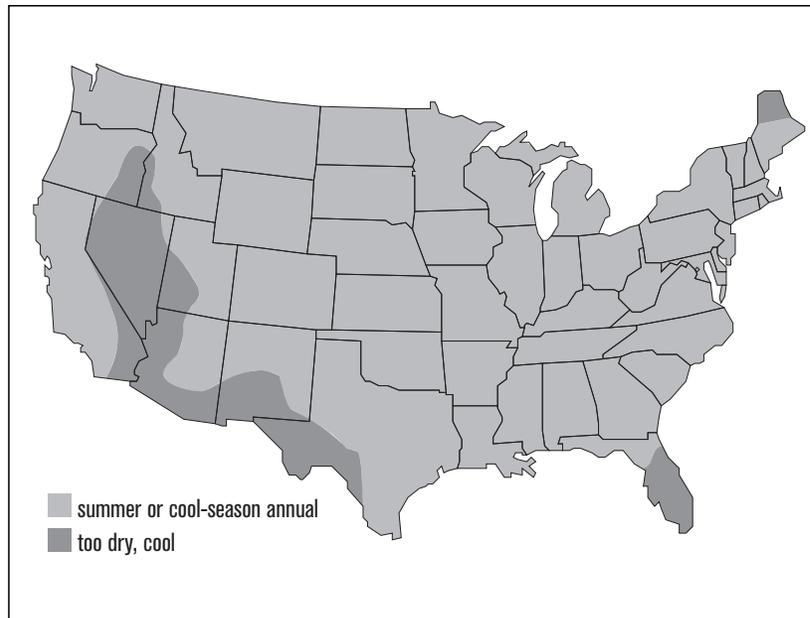
Fagopyrum esculentum

Type: summer or cool-season annual broadleaf grain

Roles: quick soil cover, weed suppressor, nectar for pollinators and beneficial insects, topsoil loosener, rejuvenator for low-fertility soils

Mix with: sorghum-sudangrass hybrids, sunn hemp

See charts, pp. 66 to 72, for ranking and management summary.



Buckwheat is the speedy short-season cover crop. It establishes, blooms and reaches maturity in just 70 to 90 days and its residue breaks down quickly. Buckwheat suppresses weeds and attracts beneficial insects and pollinators with its abundant blossoms. It is easy to kill, and reportedly extracts soil phosphorus from soil better than most grain-type cover crops.

Buckwheat thrives in cool, moist conditions but it is not frost tolerant. Even in the South, it is not grown as a winter annual. Buckwheat is not particularly drought tolerant, and readily wilts under hot, dry conditions. Its short growing season may allow it to avoid droughts, however.

BENEFITS

Quick cover. Few cover crops establish as rapidly and as easily as buckwheat. Its rounded pyramid-shaped seeds germinate in just three to five days. Leaves up to 3 inches wide can develop within two weeks to create a relatively dense, soil shading canopy. Buckwheat typically produces only 2 to 3 tons of dry matter per acre, but it does so quickly—in just six to eight weeks (257). Buckwheat residue also decomposes quickly, releasing nutrients to the next crop.

Weed suppressor. Buckwheat's strong weed-suppressing ability makes it ideal for smothering

warm-season annual weeds. It's also planted after intensive, weed-weakening tillage to crowd out perennials. A mix of tillage and successive dense seedings of buckwheat can effectively suppress Canada thistle, sowthistle, creeping jenny, leafy spurge, Russian knapweed and perennial peppergrass (257). While living buckwheat may have an allelopathic weed-suppressing effect (351), its primary impact on weeds is through shading and competition.

Phosphorus scavenger. Buckwheat takes up phosphorus and some minor nutrients (possibly including calcium) that are otherwise unavailable to crops, then releasing these nutrients to later crops as the residue breaks down. The roots of the plants produce mild acids that release nutrients from the soil. These acids also activate slow-releasing organic fertilizers, such as rock phosphate. Buckwheat's dense, fibrous roots cluster in the top 10 inches of soil, providing an extensive root surface area for nutrient uptake.

Thrives in poor soils. Buckwheat performs better than cereal grains on low-fertility soils and soils with high levels of decaying organic matter. That's why it was often the first crop planted on cleared land during the settlement of woodland areas and is still a good first crop for rejuvenating over-farmed soils. However, buckwheat does not do well in compacted, droughty or excessively wet soils.

Quick regrowth. Buckwheat will regrow after mowing if cut before it reaches 25 percent bloom. It also can be lightly tilled after the midpoint of its long flowering period to reseed a second crop. Some growers bring new land into production by raising three successive buckwheat crops this way.

Soil conditioner. Buckwheat's abundant, fine roots leave topsoil loose and friable after only minimal tillage, making it a great mid-summer soil conditioner preceding fall crops in temperate areas.

Nectar source. Buckwheat's shallow white blossoms attract beneficial insects that attack or para-



Marianne Sarrantonio

BUCKWHEAT (Fagopyrum esculentum)

sitize aphids, mites and other pests. These beneficials include hover flies (*Syrphidae*), predatory wasps, minute pirate bugs, insidious flower bugs, tachinid flies and lady beetles. Flowering may start within three weeks of planting and continue for up to 10 weeks.

Nurse crop. Due to its quick, aggressive start, buckwheat is rarely used as a nurse crop, although it can be used anytime you want quick cover. It is sometimes used to protect late-fall plantings of slow-starting, winter-hardy legumes wherever freezing temperatures are sure to kill the buckwheat.

MANAGEMENT

Buckwheat prefers light to medium, well-drained soils—sandy loams, loams, and silt loams. It performs poorly on heavy, wet soils or soils with high levels of limestone. Buckwheat grows best in cool, moist conditions, but is not frost-tolerant. It is also not drought tolerant. Extreme afternoon heat will cause wilting, but plants bounce back overnight.

Establishment

Plant buckwheat after all danger of frost. In untilled, minimally tilled or clean-tilled soils, drill 50 to 60 lb./A at $\frac{1}{2}$ to $1\frac{1}{2}$ inches deep in 6 to 8

inch rows. Use heavier rates for quicker canopy development. For a fast smother crop, broadcast up to 96 lb./A (2 bu./A) onto a firm seedbed and incorporate with a harrow, tine weeder, disk or field cultivator. Overall vigor is usually better in drilled seedings. As a nurse-crop for slow-

**Buckwheat
germinates and
grows quickly,
producing 2 to 3
tons of dry
matter in just
6 to 8 weeks.**

growing, winter annual legumes planted in late summer or fall, seed at one-quarter to one-third of the normal rate.

Buckwheat compensates for lower seeding rates by developing more branches per plant and more seeds per blossom. However, skimping too much on seed makes stands more vulnerable to early weed

competition until the canopy fills in. Using cleaned, bin-run or even birdseed-grade seed can lower establishment costs, but increases the risk of weeds. As denser stands mature, stalks become spindly and are more likely to lodge from wind or heavy rain.

Rotations

Buckwheat is used most commonly as a mid-summer cover crop to suppress weeds and replace bare fallow. In the Northeast and Midwest, it is often planted after harvest of early vegetable crops, then followed by a fall vegetable, winter grain, or cool-season cover crop. Planted later, winterkilled residue provides decent soil cover and is easy to no-till into. In many areas, it can be planted following harvest of winter wheat or canola.

In parts of California, buckwheat grows and flowers between the killing of winter annual legume cover crops in spring and their re-establishment in fall. Some California vineyard managers seed 3-foot strips of buckwheat in row middles, alternating it and another summer cover crop, such as sorghum-sudangrass.

Buckwheat is sensitive to herbicide residues from previous crops, especially in no-till seedbeds. Residue from trifluralin and from triazine and sulfonyleurea herbicides have damaged or killed buckwheat seedlings (79). When in doubt, sow and water a small test plot of the fast-germinating seed to detect stunting or mortality.

Pest Management

Few pests or diseases bother buckwheat. Its most serious weed competitors are often small grains from preceding crops, which only add to the cover crop biomass. Other grass weeds can be a problem, especially in thin stands. Weeds also can increase after seed set and leaf drop. Diseases include a leaf spot caused by the fungus *Ramularia* and *Rhizoctonia* root rot.

Other Options

Plant buckwheat as an emergency cover crop to protect soil and suppress weeds when your main crop fails or cannot be planted in time due to unfavorable conditions.

To assure its role as habitat for beneficial insects, allow buckwheat to flower for at least 20 days—the time needed for minute pirate bugs to produce another generation.

Buckwheat can be double cropped for grain after harvesting early crops if planted by mid-July in northern states or by early August in the South. It requires a two-month period of relatively cool, moist conditions to prevent blasting of the blossoms. There is modest demand for organic and specially raised food-grade buckwheat in domestic and overseas markets. Exporters usually specify variety, so investigate before planting buckwheat for grain.

Management Cautions

Buckwheat can become a weed. Kill within 7 to 10 days after flowering begins, before the first seeds begin to harden and turn brown. Earliest maturing seed can shatter before plants finish blooming. Some seed may overwinter in milder regions.

Buckwheat can harbor insect pests including Lygus bugs, tarnished plant bugs and *Pratylinchus penetrans* root lesion nematodes (256).

Clark, Andy (ed.). 2007. *Managing Cover Crops Profitably*, 3rd ed. Sustainable Agriculture Network, Beltsville, MD.

COMPARATIVE NOTES

- Buckwheat has only about half the root mass as a percent of total biomass as small grains (355). Its succulent stems break down quickly, leaving soils loose and vulnerable to erosion, particularly after tillage. Plant a soil-holding crop as soon as possible.
- Buckwheat is nearly three times as effective as barley in extracting phosphorus, and more than 10 times more effective than rye—the poorest P scavenger of the cereal grains (355).
- As a cash crop, buckwheat uses only half as much soil moisture as soybeans (299).

Seed sources. See *Seed Suppliers* (p. 195). 🌱

OATS

Avena sativa

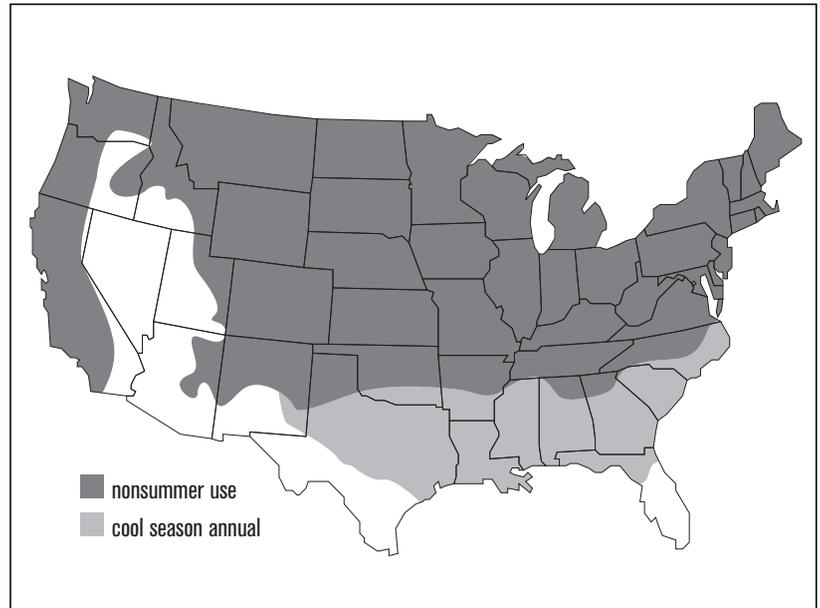
Also called: spring oats

Type: cool season annual cereal

Roles: suppress weeds, prevent erosion, scavenge excess nutrients, add biomass, nurse crop

Mix with: clover, pea, vetch, other legumes or other small grains

See charts, pp. 66 to 72, for ranking and management summary.



If you need a low-cost, reliable fall cover that winterkills in Hardiness Zone 6 and colder and much of Zone 7, look no further. Oats provide quick, weed-suppressing biomass, take up excess soil nutrients and can improve the productivity of legumes when planted in mixtures. The cover's fibrous root system also holds soil during cool-weather gaps in rotations, and the ground cover provides a mellow mulch before low-till or no-till crops.

An upright, annual grass, oats thrive under cool, moist conditions on well-drained soil. Plants can reach heights in excess of 4 feet. Stands generally fare poorly in hot, dry weather.

BENEFITS

You can depend on oats as a versatile, quick-growing cover for many benefits:

Affordable biomass. With good growing conditions and sound management (including timely planting), expect 2,000 to 4,000 pounds of dry matter per acre from late-summer/early fall-seeded oats and up to 8,000 pounds per acre from spring stands.

Nutrient catch crop. Oats take up excess N and small amounts of P and K when planted early

enough. Late-summer plantings can absorb as much as 77 lb. N/A in an eight- to ten-week period, studies in the Northeast and Midwest have shown (313, 329).

Where the plant winterkills, some farmers use oats as a nitrogen catch crop after summer legume plowdowns, to hold some N over winter without needing to kill the cover in spring. Some

Oats are a reliable, low-cost cover that winterkill in Zone 6 and much of Zone 7.

of the N in the winterkilled oats may still be lost by spring, either through denitrification into the atmosphere or by leaching from the soil profile. Consider mixing oats with an overwintering legume if your objective is to maximize N contribution to the next crop.

Smother crop. Quick to germinate, oats are a great smother crop that outcompetes weeds and also provides allelopathic residue that can hinder germination of many weeds—and some crops (see below)—for a few weeks. Reduce crop suppression concerns by waiting two- to three weeks after killing oats before planting a subsequent crop.

Fall legume nurse crop. Oats have few equals as a legume nurse crop or companion crop. They can increase the fertilizer replacement value of legumes. Adding about 35 to 75 lb. oats/A to the seeding mix helps slow-establishing legumes such as hairy vetch, clovers or winter peas, while increasing biomass. It also helps reduce fall weeds. The oats will winterkill in many areas while improving the legume's winter survival.

Spring green manure or companion crop. Spring-seeded with a legume, oats can provide hay or grain and excellent straw in the Northern U.S., while the legume remains as a summer—or even later—cover. There's also a haylage option with a fast-growing legume if you harvest when oats are in the dough stage. The oats will increase the dry matter yield and boost the total protein,

but, because of its relatively high nitrogen content, could pose a nitrate-poisoning threat to livestock, especially if you delay harvesting until oats are nearing the flowering stage.

The climbing growth habit of some viny legumes such as vetch can contribute to lodging and make oat grain harvest difficult. If you're growing the legume for seed, the oats can serve as a natural trellis that eases combining.

MANAGEMENT

Establishment & Fieldwork

Time seeding to allow at least six to 10 weeks of cool-season growth. Moderately fertile soil gives the best stands.

Late-summer/early-fall planting. For a winterkilled cover, spring oats usually are seeded in late summer or early fall in Zone 7 or colder. Broadcasting or overseeding will give the best results for the least cost, unless seeding into heavy residue. Cleaned, bin-run seed will suffice.

If broadcasting and you want a thick winterkilled mulch, seed at the highest locally recommended rate (probably 3 to 4 bushels per acre) at least 40 to 60 days before your area's first killing frost. Assuming adequate moisture for quick germination, the stand should provide some soil-protecting, weed-suppressing mulch.

Disk lightly to incorporate. In many regions, you'll have the option of letting it winterkill or sending in cattle for some fall grazing.

If seeding oats as a fall nurse crop for a legume, a low rate (1 to 2 bushels per acre) works well.

If drilling oats, seed at 2 to 3 bushels per acre $\frac{1}{2}$ to 1 inch deep, or $1\frac{1}{2}$ inches when growing grain you plan to harrow for weed control.

Shallow seeding in moist soil provides rapid emergence and reduces incidence of root rot disease.

Timing is critical when you want plenty of biomass or a thick ground cover. As a winter cover following soybeans in the Northeast or Midwest, overseeding spring oats at the leaf-yellowing or early leaf-drop stage (and with little residue present) can give a combined ground cover as high as 80 percent through early winter (200). If you

wait until closer to or after soybean harvest, however, you'll obtain much less oat biomass to help retain bean residue, Iowa and Pennsylvania studies have shown.

Delaying planting by as little as two weeks in late summer also can reduce the cover's effectiveness as a spring weed fighter, a study in upstate New York showed. By spring, oat plots that had been planted on August 25 had 39 percent fewer weed plants and one-seventh the weed biomass of control plots with no oat cover, while oats planted two weeks later had just 10 percent fewer weed plants in spring and 81 percent of the weed biomass of control plots (329, 330).

No-hassle fieldwork. As a winterkilled cover, just light disking in spring will break up the brittle oat residue. That exposes enough soil for warming and timely planting. Or, no-till directly into the mulch, as the residue will decompose readily early in the season.

Winter planting. As a fall or winter cover crop in Zone 8 or warmer, seed oats at low to medium rates. You can kill winter-planted oats with spring plowing, or with herbicides in reduced-tillage systems.

Spring planting. Seeding rate depends on your intended use: medium to high rates for a spring green manure and weed suppressor, low rates for mixtures or as a legume companion crop. Higher rates may be needed for wet soils or thicker ground cover. Excessive fertility can encourage lodging, but if you're growing oats just for its cover value, that can be an added benefit for weed suppression and moisture conservation.

Easy to kill. Oats will winterkill in most of zone 7 or colder. Otherwise, kill by mowing or spraying soon after the vegetative stage, such as the milk or soft dough stage. In no-till systems, rolling/crimping will also work (best at dough stage or later). See *Cover Crop Roller Design Holds Promise For No-Tillers*, p. 146. If speed of spring soil-warming is not an issue, you can spray or mow the oats and leave on the soil surface for mulch.



Marianne Sarrantonio

OATS (*Avena sativa*)

If you want to incorporate the stand, allow at least two to three weeks before planting the next crop.

Killing too early reduces the biomass potential and you could see some regrowth if killing mechanically. But waiting too long could make tillage of the heavier growth more difficult in a conventional tillage system and could deplete soil moisture needed for the next crop. Timely killing also is important because mature oat stands can tie up nitrogen.

Pest Management

Allelopathic (naturally occurring herbicidal) compounds in oat roots and residue can hinder weed growth for a few weeks. These compounds also can slow germination or root growth of some subsequent crops, such as lettuce, cress, timothy, rice, wheat and peas. Minimize this effect by waiting three weeks after oat killing before seeding a susceptible crop, or by following with an alternate crop. Rotary hoeing or other pre-emerge mechanical weeding of solo-seeded oats can improve annual broadleaf control.

Oats are **less prone to insect problems** than wheat or barley. If you're growing oats for grain or forage, armyworms, various grain aphids and mites, wireworms, cutworms, thrips, leafhoppers, grubs and billbugs could present occasional problems.

Oats, Rye Feed Soil in Corn/Bean Rotation

Bryan and Donna Davis like what cover crops have done for their corn/soybean rotation. They use less grass herbicide, have applied insecticides only once in the last six years, and they have seen organic matter content almost double from less than 2% to almost 4%.

Rye and oats are the cover crop mainstays on the nearly 1,000 acres they farm near Grinnell, Iowa. Bryan and Donna purchased the farm—in the family since 1929—in 1987 and almost immediately put most of the operation under 100% no-till, a system they had experimented with over the years. They now till some acres and are also in the process of transitioning 300 acres to organic.

Moving $\frac{1}{3}$ of their acreage toward organic seems the logical culmination of the Davis' makeover of their farm that started with a desire to “get away from the chemicals.” That was what motivated them to start using cover crops to feed the soil and help manage pests.

“We were trying to get away from the idea that every bug and weed must be exterminated. Rather, we need to ‘manage’ the system and tolerate some weed and insect pressure. It should be more of a balance,” says Bryan.

Bryan and Donna are practitioners and proponents of “biological farming,” a systems approach based on such principles as feeding the soil to keep it biologically active, reducing chemical inputs and paying attention to trace elements or micronutrients in order to maintain balance in the system. Cover crops play an integral role in this system.

They seed oats at 2-3 bu/A in spring or fall, depending on time and labor availability. Donna does most of the combining and planting, but even with a lot of acres for two people to manage, cover crops are a high priority on their schedule. Fall-seeded oats are planted after soybean harvest and “need rain on them soon after planting to get them started.” They'll put on about a foot of growth before winterkilling, usually in December in their south-central Iowa conditions.

Spring oats are broadcast in mid or late March with a fertilizer cart and then rotary harrowed. If going back to corn, they seed at a heavier, 3.5 bu rate, expecting only about 5 or 6 weeks of growth before they work down the cover crop with a soil finisher and plant corn in early May. For soybeans, they either kill chemically and no-till the beans, or work down and seed conventionally.

They have managed rye in different ways over the years depending on its place in the rotation, but prefer to seed into killed or tilled rye rather than a living cover crop. They figure that they get about 35 lb. N from oats and up to 60 lb. from rye.

On their organic transition acres they are applying chicken manure (2 tons/A), and cover crops are crucial to sopping up excess nutrients and crowding out the weeds that crop up in response to the extra nutrients. They feel that their efforts to balance nutrients are also helping with weed control, because weeds feed on nutrient imbalances.

In addition to the increase in soil organic matter, attributed to cover crops and no-tillage, they've also seen improvements in soil moisture and infiltration. Fields that used to pond after heavy rains no longer do. Soybeans are weathering drought better, and corn stays green longer during a “more natural” drying down process.

“Our system takes more time and is more labor intensive, but if you look at the whole budget, we are doing much better now. We have cut our chemical costs dramatically, and have reduced fertility costs—in some fields—by $\frac{1}{3}$ to $\frac{1}{2}$,” says Bryan. “With energy costs these days, you can't afford not to do this.”

Davis is careful to note that this is not just about adding one component such as cover crops. “You need to address the whole system, not just one piece of the pie. To be able to have a sustaining system, you must work with the living system. Feed the soil and give it a roof over its head.” Cover crops play a crucial role in that system.

—Andy Clark

Resistant oat varieties can minimize rusts, smuts and blights if they are a concern in your area or for your cropping system. Cover crops such as oats help reduce root-knot nematodes and vegetable crop diseases caused by *Rhizoctonia*, results of a producer study in South Carolina show (448), although brassicas are better. To reduce harmful nematodes that oats could encourage, avoid planting oats two years in a row or after nematode-susceptible small grains such as wheat, rye or triticale (71).

Other Options

There are many low-cost, regionally adapted and widely available oat varieties, so you have **hay, straw, forage or grain options**. Select for cultural and local considerations that best fit your intended uses. Day-length, stalk height, resistance to disease, dry matter yield, grain test weight and other traits may be important considerations. In the Deep South, fast-growing black oats (*Avena strigosa*) look promising as a weed-suppressive cover for soybeans. See *Up-and-Coming Cover Crops* (p. 191).

Aside from their value as a cover crop, oats are a great feed supplement, says grain and hog farmer Carmen Fernholz, Madison, Minn. A niche

market for organic oats also could exist in your area, he observes.

Oats are more palatable than rye and easily overgrazed. If using controlled grazing in oat stands, watch for high protein levels, which can vary from 12 to 25 percent (434). The potassium level of oat hay also is sometimes very high and could cause metabolic problems in milking cows if it's the primary forage. Underseeding a legume enhances the forage option for oats by increasing the biomass (compared with solo-cropped oats) and providing nitrogen for a subsequent crop.

COMPARATIVE NOTES

- Fall brassicas grow faster, accumulate more N and may suppress weeds, nematodes and disease better than oats.
- Rye grows more in fall and early spring, absorbs more N and matures faster, but is harder to establish, to kill and to till than oats.
- As a legume companion/nurse crop, oats outperform most varieties of other cereal grains.
- Oats are more tolerant of wet soil than is barley, but require more moisture.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

RYE

Secale cereale

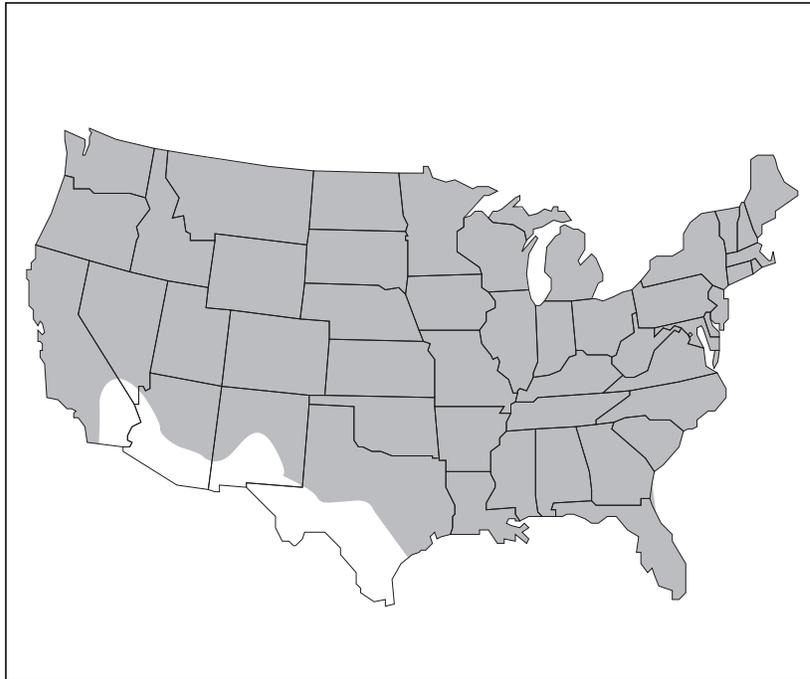
Also called: cereal rye, winter rye, grain rye

Type: cool season annual cereal grain

Roles: scavenge excess N, prevent erosion, add organic matter, suppress weeds

Mix with: legumes, grasses or other cereal grains

See charts, pp. 66 to 72, for ranking and management summary.



The hardiest of cereals, rye can be seeded later in fall than other cover crops and still provide considerable dry matter, an extensive soil-holding root system, significant reduction of nitrate leaching and exceptional weed suppression. Inexpensive and easy to establish, rye outperforms all other cover crops on infertile, sandy or acidic soil or on poorly prepared land. It is widely adapted, but grows best in cool, temperate zones.

Taller and quicker-growing than wheat, rye can serve as a windbreak and trap snow or hold rainfall over winter. It overseeds readily into many high-value and agronomic crops and resumes growth quickly in spring, allowing timely killing by rolling, mowing or herbicides. Pair rye with a winter annual legume such as hairy vetch to offset rye's tendency to tie up soil nitrogen in spring.

BENEFITS

Nutrient catch crop. Rye is the best cool-season cereal cover for absorbing unused soil N. It has no taproot, but rye's quick-growing, fibrous root system can take up and hold as much as 100 lb. N/A until spring, with 25 to 50 lb. N/A more typical (422). Early seeding is better than late seeding for scavenging N (46).

- A Maryland study credited rye with holding 60 percent of the residual N that could have leached from a silt loam soil following intentionally over-fertilized corn (372).
- A Georgia study estimated rye captured from 69 to 100 percent of the residual N after a corn crop (220).
- In an Iowa study, overseeding rye or a rye/oats mix into soybeans in August limited leaching loss from September to May to less than 5 lb. N/A (313).

Rye increases the concentration of exchangeable potassium (K) near the soil surface, by bringing it up from lower in the soil profile (123).

Rye's rapid growth (even in cool fall weather) helps trap snow in winter, further boosting winterhardness. The root system promotes better drainage, while rye's quick maturity in spring—compared with other cover crops—can help conserve late-spring soil moisture.

Reduces erosion. Along with conservation tillage practices, rye provides soil protection on sloping fields and holds soil loss to a tolerable level (124).

Fits many rotations. In most regions, rye can serve as an overwintering cover crop after corn or before or after soybeans, fruits or vegetables. It's not the best choice before a small grain crop such as wheat or barley unless you can kill rye reliably and completely, as volunteer rye seed would lower the value of other grains.

Rye also works well as a strip cover crop and windbreak within vegetables or fruit crops and as a quick cover for rotation gaps or if another crop fails.

You can overseed rye into vegetables and tasseling or silking corn with consistently good results. You also can overseed rye into brassicas (369, 422), into soybeans just before leaf drop or between pecan tree rows (61).

Plentiful organic matter. An excellent source of residue in no-till and minimum-tillage systems and as a straw source, rye provides up to 10,000 pounds of dry matter per acre, with 3,000 to 4,000 pounds typical in the Northeast (118, 361). A rye cover crop might yield too much residue, depending on your tillage system, so be sure your planting regime for subsequent crops can handle this. Rye overseeded into cabbage August 26 covered nearly 80 percent of the between-row plots by mid-October and, despite some summer heat, already had accumulated nearly half a ton of biomass per acre in a New York study. By the May 19 plowdown, rye provided 2.5 tons of dry matter per acre and had accumulated 80 lb. N/A. Cabbage yields weren't affected, so competition wasn't a problem (329).

Weed suppressor. Rye is one of the best cool season cover crops for outcompeting weeds, especially small-seeded, light-sensitive annuals such as lambsquarters, redroot pigweed, velvetleaf, chickweed and foxtail. Rye also suppresses many weeds allelopathically (as a natural herbicide), including dandelions and Canada thistle and has been shown to inhibit germination of some triazine-resistant weeds (336).

Rye reduced total weed density an average of 78 percent when rye residue covered more than 90 percent of soil in a Maryland no-till study (410), and

by 99 percent in a California study (422). You can increase rye's weed-suppressing effect before no-till corn by planting rye with an annual legume such as hairy vetch. Don't expect complete weed control, however. You'll probably need complementary weed management measures.

Pest suppressor. While rye is susceptible to the same insects that attack other cereals, serious infestations are rare. Rye reduces insect pest problems in rotations (448) and attracts significant numbers of beneficials such as lady beetles (56).

Fewer diseases affect rye than other cereals. Rye can help reduce root-knot nematodes and other harmful nematodes, research in the South suggests (20, 448).

Rye can be planted later in fall than other cover crops.

Companion crop/legume mixtures. Sow rye with legumes or other grasses in fall or overseed a legume in spring. A legume helps offset rye's tendency to tie up N. A legume/rye mixture adjusts to residual soil N levels. If there's plenty of N, rye tends to do better; if there is insufficient N, the legume component grows better, Maryland research shows (86). Hairy vetch and rye are a popular mix, allowing an N credit before corn of 50 to 100 lb. N/A. Rye also helps protect the less hardy vetch seedlings through winter.

MANAGEMENT

Establishment & Fieldwork

Rye prefers light loams or sandy soils and will germinate even in fairly dry soil. It also will grow in heavy clays and poorly drained soils, and many cultivars tolerate waterlogging (63).

Rye can establish in very cool weather. It will germinate at temperatures as low as 34° F. Vegetative growth requires 38° F or higher (361).

Winter annual use. Seed from late summer to midfall in Hardiness Zones 3 to 7 and from fall to midwinter in Zones 8 and warmer. In the Upper

Midwest and cool New England states, seed two to eight weeks earlier than a wheat or rye grain crop to ensure maximum fall, winter and spring growth. Elsewhere, your tillage system and the amount of fall growth you prefer will help determine planting date. Early planting increases the amount of N taken up before winter, but can make field management (especially killing the cover crop and tillage) more difficult in spring. See *Rye Smothers Weeds Before Soybeans* (p. 104).

Rye is more sensitive to seeding depth than other cereals, so plant no deeper than 2 inches (71). Drill 60 to 120 lb./A (1 to 2 bushels) into a prepared seedbed or broadcast 90 to 160 lb./A (1.5 to 3 bushels) and disk lightly or cultipack (361, 422).

If broadcasting late in fall and your scale and budget allow, you can increase the seeding rate to as high as 300 or 350 lb./A (about 6 bushels) to ensure an adequate stand. Rye can be overseed by air more consistently than many other cover crops.

"I use a Buffalo Rolling Stalk Chopper to help shake rye seeds down to the soil surface," says Steve Groff, a Holtwood, Pa., vegetable grower. "It's a very consistent, fast and economical way to establish rye in fall." (Groff's farming system is described in detail at www.cedarmeadowfarm.com).

Mixed seeding. Plant rye at the lowest locally recommended rate when seeding with a legume (361), and at low to medium rates with other grasses. In a Maryland study, a mix of 42 pounds of rye and 19 pounds of hairy vetch per acre was the optimum fall seeding rate before no-till corn on a silt loam soil (81). If planting with clovers, seed rye at a slightly higher rate, about 56 lb. per acre.

For transplanting tomatoes into hilly, erosion-prone soil, Steve Groff fall-seeds a per-acre mix of 30 pounds rye, 25 pounds hairy vetch and 10 pounds crimson clover. He likes how the three-way mix guarantees biomass, builds soil and provides N.

Spring seeding. Although it's not a common practice, you can spring seed cereals such as rye as a weed-suppressing companion, relay crop or early forage. Because it won't have a chance to vernalize (be exposed to extended cold after ger-



Marianne Sarrantonio

CEREAL RYE (*Secale cereale*)

mination), the rye can't set seed and dies on its own within a few months in many areas. This provides good weed control in asparagus, says Rich de Wilde, Viroqua, Wis.

After drilling a large-seeded summer crop such as soybeans, try broadcasting rye. The cover grows well if it's a cool spring, and the summer crop takes off as the temperature warms up. Secondary tillage or herbicides would be necessary to keep the rye in check and to limit the cover crop's use of soil moisture.

Killing & Controlling

Nutrient availability concern. Rye grows and matures rapidly in spring, but its maturity date varies depending on soil moisture and temperature. Tall and stemmy, rye immobilizes N as it decomposes. The N tie-up varies directly with the maturity of the rye. Mineralization of N is very slow, so don't count on rye's overwintered N becoming available quickly.

Killing rye early, while it's still succulent, is one way to minimize N tie-up and conserve soil moisture. But spring rains can be problematic with rye, especially before an N-demanding crop, such as corn. Even if plentiful moisture hastens the optimal kill period, you still might get too much rain in the following weeks and have significant nitrate leaching, a Maryland study showed (109). Soil compaction also could be a problem if you're mowing rye with heavy equipment.

Late killing of rye can deplete soil moisture and could produce more residue than your tillage system can handle. For no-till corn in humid climates, however, summer soil-water conservation by cover crop residues often was more important than spring moisture depletion by growing cover crops, Maryland studies showed (82, 84, 85).

Legume combo maintains yield. One way to offset yield reductions from rye's immobilization of N would be to increase your N application. Here's another option: Growing rye with a legume allows you to delay killing the covers by a few weeks and sustain yields, especially if the legume is at least half the mix. This gives the legume more time to fix N (in some cases doubling the N contribution) and rye more time to scavenge a little more leachable N. Base the kill date on your area's normal kill date for a pure stand of the legume (109).

A legume/rye mix generally increases total dry matter, compared with a pure rye stand. The higher residue level can conserve soil moisture. For best results, wait about 10 days after killing the covers before planting a crop. This ensures adequate soil warming, dry enough conditions for planter coulters to cut cleanly and minimizes allelopathic effects from rye residue (84, 109). If using a herbicide, you might need a higher spray volume or added pressure for adequate coverage. Legume/rye mixes can be rolled once the legume is at full bloom (303).

Kill before it matures. Tilling under rye usually eliminates regrowth, unless the rye is less than 12 inches tall (361, 422). Rye often is plowed or disked in the Midwest when it's about 20 inches tall (307). Incorporating the rye before it's 18 in. high could decrease tie-up of soil N (361, 422). In Pennsylvania (118) and elsewhere, kill at least 10 days before planting corn.

For best results when mow-killing rye, wait until it has begun flowering. A long-day plant, rye is encouraged to flower by 14 hours of daylight and a temperature of at least 40° F. A sickle bar mower can give better results than a flail mower, which causes matting that can hinder emergence of subsequent crops (116).

Mow-kill works well in the South after rye sheds pollen in late April (101). If soil moisture is adequate, you can plant cotton three to five days after mowing rye when row cleaners are used in reduced-tillage systems.

Some farmers prefer to chop or mow rye by late boot stage, before it heads or flowers. "If rye gets away from you, you'd be better off baling it or harvesting it for seed," cautions southern Illinois organic grain farmer Jack Erisman (38). He often over-winters cattle in rye

Rye is the best cool-season cover crop for scavenging N, typically carrying 25 to 50 lb. N/A over to spring.

fields that precede soybeans. But he prefers that soil temperature be at least 60° F before planting beans, which is too late for him to no-till beans into standing rye.

"If rye is at least 24 inches tall, I control it with a rolling stalk chopper that thoroughly flattens and crimps the rye stems," says Pennsylvania vegetable grower Steve Groff. "That can sometimes eliminate a burndown herbicide, depending on the rye growth stage and next crop."

A heavy duty rotavator set to only 2 inches deep does a good job of tilling rye, says Rich de Wilde, Viroqua, Wis.

Can't delay a summer planting by a few weeks while waiting for rye to flower? If early rye cultivars aren't available in your area and you're in Zone 5 or colder, you could plow the rye and use secondary tillage. Alternately, try a knockdown herbicide and post-emergent herbicide or spot-spraying for residual weed control.

For quicker growth of a subsequent crop such as corn or soybeans, leave the residue upright after killing (rather than flat). That hastens crop development—unless it's a dry year—via warmer soil temperatures and a warmer seed zone, according to a three-year Ontario study (146). This rarely influences overall crop yield, however, unless you plant too early and rye residue or low soil temperature inhibits crop germination.

Cereal Rye: Cover Crop Workhorse

Talk to farmers across America about cover crops and you'll find that most of them have planted a cereal rye cover crop. Almost certainly the most commonly planted cover crop, cereal rye can now be seen growing on millions of acres of farmland each year.

There are almost as many ways to manage cover crop rye as there are farmers using it. Climate, production system, soil type, equipment and labor are the principal factors that will determine how you manage rye. Your own practical experience will ultimately determine what works best for you.

Check out how others are managing rye in this book, on the Web and around your region. Test alternative management practices that allow you to seed earlier or manage cover crop residue differently. Add a legume, a brassica or another grass to increase diversity on your farm.

Reasons for rye's widespread use include:

- It is winter-hardy, allowing it to grow longer into fall and resume growth earlier in the spring than most other cover crops.
- It produces a lot of biomass, which translates into a long-lasting residue cover in conservation tillage systems.
- It crowds out and out-competes winter annual weeds, while rye residue helps suppress summer weeds.
- It scavenges nutrients—particularly nitrogen—very effectively, helping keep nutrients on the farm and out of surface and ground water.
- It is relatively inexpensive and easy to seed.
- It works well in mixtures with legumes, resulting in greater biomass production and more complete fall/winter ground cover.
- It can be used as high-quality forage, either grazed or harvested as ryelage.
- It can fit into many different crop and livestock systems, including corn/soybean rotations, early or late vegetable crops, and dairy or beef operations.

Fall management (planting):

- While results are best if you plant rye by early fall, it also can be planted in November or December in much of the country—even into January in the deep South—and still provide tangible benefits.
- It can be drilled or broadcast after main crop harvest, with or without cultivation.
- It can be seeded before main crop harvest, usually by broadcasting, sometimes by plane or helicopter, and in northern climates, at last cultivation of the cash crop. Soil moisture availability is crucial to many of these pre-harvest seeding methods, either for germination of the cover crop or to avoid competition for water with the main crop.

Spring management (termination) is even more diverse:

- Rye can be killed with tillage, mowing, rolling or spraying.
- It can be killed before or after planting the cash crop, which can be drilled into standing cover crops in conservation tillage systems.
- Some want to leave rye growing as long as possible; others insist on terminating it as soon as possible in spring.
- Vegetable growers may leave walls of standing rye all season long between crop rows, usually to alleviate wind erosion.

Some examples of rye management wisdom from practitioners around the country:

- Pat Sheridan Jr., Fairgrove, Mich. Continuous no-till corn, sugar beets, soybeans, dry beans: "In late August, we fly rye into standing corn (or soybeans if we're coming back with soybeans the following year). We learned that rye is easier to burn down when it's more than two feet tall than when it has grown only a foot or less."
- Barry Martin, Hawksville, Ga. Peanuts and cotton. "After cotton, in late October or

November, we use a broadcast spreader (two bushels of rye per acre), then shred or mow to cover the seed. We usually get enough moisture in November and December for germination. After peanuts, we use a double disc grain drill (1.5 bushels of rye per acre) in mid-September to mid-October.”

- Bryan and Donna Davis, Grinnell, Iowa. Corn, soybeans, hay. “We tried to no-till corn and beans into rye three feet tall, but failed. The C:N ratio was way out of whack. The corn looked like it had been sprayed. If you don’t kill before planting, you will invite insects.” See also *Oats, Rye Feed Soil in Corn/Bean Rotation*, p. 96.

- Ed Quigley, Spruce Creek, PA. Dairy. “We seed cereal rye (two bushels per acre) immediately after corn silage. We allow as much spring growth as possible up to about 10 inches, at which point it becomes more difficult to kill, especially with cool/overcast conditions. We will also wait to make rylage in spring if we need feed, and then plant corn a bit later.”

In some areas, farmers substitute other small grain cover crops for rye. They are doing so to better fit their particular niches, better manage their systems, or to cut costs by saving small grain seeds. Wheat is a popular alternative to rye. Look around and experiment!

—Andy Clark

Pest Management

Thick stands ensure excellent weed suppression. To extend rye’s weed-management benefits, you can allow its allelopathic effects to persist longer by leaving killed residue on the surface rather than incorporating it. Allelopathic effects usually taper off after about 30 days. After killing rye, it’s best to wait three to four weeks before planting small-seeded crops such as carrots or onions. If strip tilling vegetables into rye, be aware that rye seedlings have more allelopathic compounds than more mature rye residue. Transplanted vegetables, such as tomatoes, and larger-seeded species, especially legumes, are less susceptible to rye’s allelopathic effects (117).

In an Ohio study, use of a mechanical under-cutter to sever roots when rye was at mid- to late bloom—and leaving residue intact on the soil surface (as whole plants)—increased weed suppression, compared with incorporation or mowing. The broadleaf weed reduction was comparable to that seen when sickle-bar mowing, and better than flail-mowing or conventional tillage (96).

If weed suppression is an important objective when planting a rye/legume mixture, plant early enough for the legume to establish well. Otherwise, you’re probably better off with a pure stand. Overseeding may not be cost-effective before a crop such as field corn, however. A mix of rye and

bigflower vetch (a quick-establishing, self-seeding, winter-annual legume that flowers and matures weeks ahead of hairy vetch) can suppress weeds significantly more than rye alone, while also allowing higher N accumulations (110).

“Rye can provide the best and cleanest mulch you

could want if it’s cut or baled in spring before producing viable seed,” says Rich de Wilde. Rye can become a **volunteer weed** if tilled before it’s 8 inches high, however, or if seedheads start maturing before you kill it. Minimize regrowth by waiting until rye is at least 12 inches high before incorporating or by mow-killing after flowering but before grain fill begins.

Insect pests rarely a problem. Rye can reduce insect pest problems in crop rotations, southern research suggests (448). In a number of mid-Atlantic locations, Colorado potato beetles have been virtually absent in tomatoes no-till transplanted into a mix of rye/vetch/crimson clover, perhaps because the beetles can’t navigate through the residue.

Rye can effectively suppress weeds by shading, competition and allelopathy.

Rye Smothers Weeds Before Soybeans

An easy-to-establish rye cover crop helps Napoleon, Ohio, farmer Rich Bennett enrich his sandy soil while trimming input costs in no-till soybeans. Bennett broadcasts rye at 2 bushels per acre on corn stubble in late October. He incorporates the seed with a disc and roller.

The rye usually breaks through the ground but shows little growth before winter dormancy. Seeded earlier in fall, rye would provide more residue than Bennett prefers by bean planting—and more effort to kill the cover. “Even if I don’t see any rye in fall, I know it’ll be there in spring, even if it’s a cold or wet one,” he says.

By early May, the rye is usually at least 1.5 feet tall and hasn’t started heading. He no-tills soybeans at 70 pounds per acre on 30-inch rows directly into standing rye cover crop. Then, depending on the amount of rye growth, he kills the rye with herbicide immediately after planting, or waits for more rye growth.

“If it’s shorter than 15 to 18 inches, rye won’t do a good enough job of shading out broadleaf weeds,” notes Bennett, who likes how rye suppresses foxtail, pigweed and lambsquarters. “I sometimes wait up to two weeks to get more rye residue,” he says.

“I kill the rye with 1.5 pints of Roundup per acre—about half the recommended rate. Adding 1.7 pounds of ammonium sulfate and

13 ounces of surfactant per acre makes it easier for Roundup to penetrate rye leaves,” he explains.

The cover dies in about two weeks. The slow kill helps rye suppress weeds while soybeans establish. In this system, Bennett doesn’t have to worry about rye regrowing.

Roundup Ready® beans have given him greater flexibility in this system. He used to cultivate beans twice using a Buffalo no-till cultivator. Now, depending on weed pressure (often giant ragweed and velvetleaf) he will spot treat or spray the whole field once with Roundup. Bennett figures the rye saves him \$15 to \$30 per acre in material costs and fieldwork, compared with conventional no-till systems for soybeans.

Rye doesn’t hurt his bean yields, either. Usually at or above county average, his yields range from 45 to 63 bushels per acre, depending on rainfall, says Bennett.

“I really like rye’s soil-saving benefits,” he says. “Rye reduces our winter wind erosion, improves soil structure, conserves soil moisture and reduces runoff.” Although he figures the rye’s restrained growth (from the late fall seeding) provides only limited scavenging of leftover N, any that it does absorb and hold overwinter is a bonus.

Updated in 2007 by Andy Clark

While insect infestations are rarely serious with rye, as with any cereal grain crop occasional problems occur. If armyworms have been a problem, for example, burning down rye before a corn crop could move the pests into the corn. Purdue Extension entomologists note many northeastern Indiana corn farmers reported this in 1997. Crop rotations and IPM can resolve most pest problems you might encounter with rye.

Few diseases. Expect very few diseases when growing rye as a cover crop. A rye-based mulch

can reduce diseases in some cropping systems. No-till transplanting tomatoes into a mix of rye/vetch/crimson clover, for example, consistently has been shown to delay the onset of early blight in several locations in the Northeast. The mulch presumably reduces soil splashing onto the leaves of the tomato plants.

If you want the option of harvesting rye as a grain crop, use of resistant varieties, crop rotation and plowing under crop residues can minimize rust, stem smut and anthracnose.

Other Options

Quick to establish and easy to incorporate when succulent, rye can fill rotation gaps in reduced-tillage, semi-permanent bed systems without increasing pest concerns or delaying crop plantings, a California study showed (216).

Erol Maddox, a Hebron, Md. grower, takes advantage of rye's relatively slow decomposition when double cropping. He likes transplanting spring cole crops into rye/vetch sod, chopping the cover mix at bloom stage and letting it lay until August, when he plants fall cole crops.

Mature rye isn't very palatable and provides poor-quality forage. It makes high quality hay or bage at boot stage, however, or grain can be ground and fed with other grains. Avoid feeding ergot-infected grain because it may cause abortions.

Rye can extend the grazing season in late fall and early spring. It tolerates fall grazing or mowing with little effect on spring regrowth in many areas (210). Growing a mixture of more palatable cover crops (clovers, vetch or ryegrass) can encourage regrowth even further by discouraging overgrazing (329).

Management Cautions

Although rye's extensive root system provides quick weed suppression and helps soil structure,

don't expect dramatic soil improvement from a single stand's growth. Left in a poorly draining field too long, a rye cover could slow soil and warming even further, delaying crop planting. It's also not a silver bullet for eliminating herbicides. Expect to deal with some late-season weeds in subsequent crops (410).

COMPARATIVE NOTES

- Rye is more cold- and drought-tolerant than wheat.
- Oats and barley do better than rye in hot weather.
- Rye is taller than wheat and tillers less. It can produce more dry matter than wheat and a few other cereals on poor, droughty soils but is harder to burn down than wheat or triticale (241, 361).
- Rye is a better soil renovator than oats (422), but brassicas and sudangrass provide deeper soil penetration (451).
- Brassicas generally contain more N than rye, scavenge N nearly as well and are less likely to tie up N because they decompose more rapidly.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

SORGHUM-SUDANGRASS HYBRIDS

Sorghum bicolor x *S. bicolor*
var. sudanese

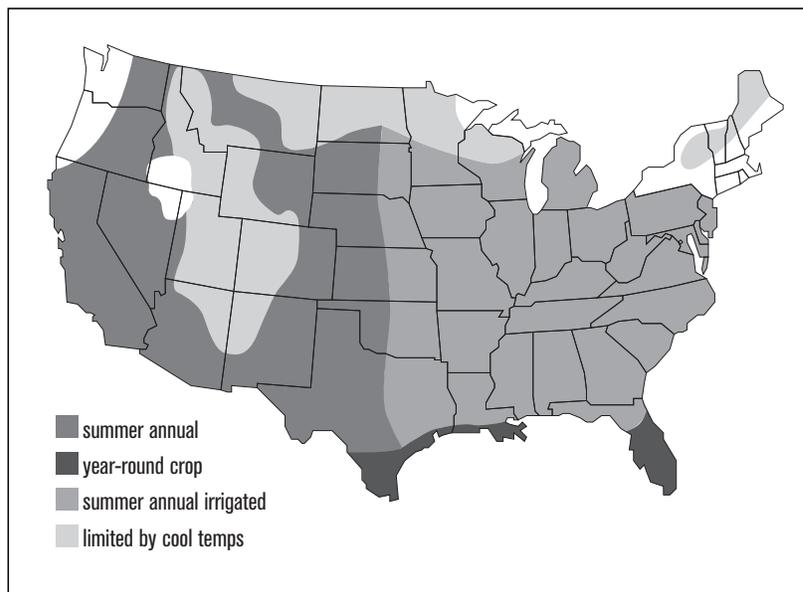
Also called: Sudex, Sudax

Type: summer annual grass

Roles: soil builder, weed and nematode suppressor, subsoil loosener

Mix with: buckwheat, sesbania, sunnhemp, forage soybeans or cowpeas

See charts, pp. 66 to 72, for ranking and management summary.



Sorghum-sudangrass hybrids are unrivaled for adding organic matter to worn-out soils. These tall, fast-growing, heat-loving summer annual grasses can smother weeds, suppress some nematode species and penetrate compacted subsoil if mowed once. Seed cost is modest. Followed by a legume cover crop, sorghum-sudangrass hybrids are a top choice for renovating overfarmed or compacted fields.

The hybrids are crosses between forage-type sorghums and sudangrass. Compared with corn, they have less leaf area, more secondary roots and a waxier leaf surface, traits that help them withstand drought (361). Like corn, they require good fertility—and usually supplemental nitrogen—for best growth. Compared with sudangrass, these hybrids are taller, coarser and more productive.

Forage-type sorghum plants are larger, leafier and mature later than *grain* sorghum plants. Compared with sorghum-sudangrass hybrids, they are shorter, less drought tolerant, and don't regrow as well. Still, forage sorghums as well as most forms of sudangrass can be used in the same cover-cropping roles as sorghum-sudangrass hybrids. All sorghum- and sudangrass-related species produce compounds that inhibit certain

plants and nematodes. They are not frost tolerant, and should be planted after the soil warms in spring or in summer at least six weeks before first frost.

BENEFITS

Biomass producer. Sorghum-sudangrass grows 5 to 12 feet tall with long, slender leaves, stalks up to one-half inch in diameter and aggressive root systems. These features combine to produce ample biomass, usually about 4,000 to 5,000 lb. DM/A. Up to 18,000 lb. DM/A has been measured with multiple cuttings on fertile soils with adequate moisture.

Subsoil aerator. Mowing whenever stalks reach 3 to 4 feet tall increases root mass five to eight times compared with unmowed stalks, and forces the roots to penetrate deeper.

In addition, tops grow back green and vegetative until frost and tillering creates up to six new, thicker stalks per plant. A single mowing on New York muck soils caused roots to burrow 10 to 16 inches deep compared to 6 to 8 inches deep for unmowed plants. The roots of mowed plants frac-

tured subsoil compaction with wormhole-like openings that improved surface drainage. However, four mowings at shorter heights caused plants to behave more like a grass and significantly decreased the mass, depth and diameter of roots (277, 450, 451).

Weed suppressor. When sown at higher rates than normally used for forage crops, sorghum-sudangrass hybrids make an effective smother crop. Their seedlings, shoots, leaves and roots secrete allelopathic compounds that suppress many weeds. The main root exudate, **sorgholeone**, is strongly active at extremely low concentrations, comparable to those of some synthetic herbicides (370). As early as five days after germination, roots begin secreting this allelochemical, which persists for weeks and has visible effects on lettuce seedlings even at 10 parts per million (440).

Sorghum-sudangrass hybrids suppress such annual weeds as velvetleaf, large crabgrass, barnyardgrass (126, 305), green foxtail, smooth pigweed (190), common ragweed, redroot pigweed and purslane (316). They also suppressed pine (214) and redbud tree seedlings in nursery tests (154). The residual weed-killing effects of these allelochemicals increased when sorghum-sudangrass hybrids were treated with the herbicides sethoxydim, glyphosate or paraquat, in descending order of magnitude (144).

Nematode and disease fighter. Planting sorghum-sudangrass hybrids instead of a host crop is a great way to disrupt the life cycles of many diseases, nematodes and other pests. For example, when sorghum-sudangrass or sorghum alone were no-tilled into endophyte-infected fescue pastures in Missouri that had received two herbicide applications, the disease was controlled nearly 100 percent. No-till reseeding with endophyte-free fescue completed this cost-effective renovation that significantly improved the rate of gain of yearling steers (16).

Renews farmed-out soils. The combination of abundant biomass production, subsoiling root sys-



Marianne Sarrantonio

SORGHUM-SUDANGRASS (Sorghum bicolor X S. bicolor var. sudanese)

tems, and weed and nematode suppression can produce dramatic results.

On a low-producing muck field in New York where onion yields had fallen to less than a third of the local average, a single year of a dense planting of sorghum-sudangrass hybrid restored the soil to a condition close to that of newly cleared land (217).

Widely adapted. Sorghum-sudangrass hybrids can be grown throughout the U.S. wherever rainfall is adequate and soil temperature reaches 65° F to 70° F at least two months before frost. Once established, they can withstand drought by going nearly dormant. Sorghum-sudangrass hybrids tolerate pH as high as 9.0, and are often used in rotation with barley to reclaim alkaline soil (421). They tolerate pH as low as 5.0.

Quick forage. Sorghum-sudangrass is prized as summer forage. It can provide quick cover to prevent weeds or erosion where legume forages have been winterkilled or flooded out. Use care because these hybrids and other sorghums can produce prussic acid poisoning in livestock. Grazing poses the most risk to livestock when plants are young (up to 24 inches tall), drought stressed or killed by frost. Toxicity danger varies between cultivars.

MANAGEMENT

Establishment

Plant sorghum-sudangrass when soils are warm and moist, usually at least two weeks after the prime corn-planting date for your area. It will tolerate low-fertility, moderate acidity and high alkalinity, but prefers good fertility and near-neutral pH (361). Standard biomass production usually requires 75 to 100 lb. N/A .

With sufficient surface moisture, broadcast 40 to 50 lb./A, or drill 35 to 40 lb./A as deep as 2 inches to reach moist soil.

These heat-loving plants are unrivaled for adding organic matter to soils.

These rates provide a quicker canopy to smother weeds than lower rates used for forage production, but they require mowing or grazing to prevent lodging.

Herbicide treatment or a pass with a mechanical weeder may be necessary if germination is spotty or perennial weeds are a problem. New York on-farm tests show that a stale seedbed method—tilling, then retilling to kill the first flush of weeds just before planting—provides effective weed control.

Warm season mixtures. Plant sorghum-sudangrass in cover crop mixtures with buckwheat or with the legumes sesbania (*Sesbania exaltata*), sunnhemp (*Crotalaria juncea*), forage soybeans (*Glycine max*) or cowpeas (*Vigna unguiculata*). Broadcast these large-seeded cover crops with the sorghum-sudangrass, then incorporate about 1 inch deep. Fast-germinating buckwheat helps suppress early weeds. Sorghum-sudangrass supports the sprawling sesbania, forage soybeans and cowpeas. Sunnhemp has an upright habit, but could compete well for light if matched with a sorghum-sudangrass cultivar of a similar height.

Field Management

Plants grow very tall (up to 12 feet), produce tons of dry matter and become woody as they mature.

This can result in an unmanageable amount of tough residue that interferes with early planting the following spring (277).

Mowing or grazing when stalks are 3 to 4 feet tall encourages tillering and deeper root growth, and keeps regrowth vegetative and less fibrous until frost. For mid-summer cuttings, leave at least 6 inches of stubble to ensure good regrowth and continued weed suppression. Delayed planting within seven weeks of frost makes mowing unnecessary and still allows for good growth before winterkilling (277, 361).

Disking while plants are still vegetative will speed decomposition. Make several passes with a heavy disk or combination tillage tool to handle the dense root masses (277). Sicklebar mowing or flail chopping before tillage will reduce the number of field operations required to incorporate the crop and speed decomposition. Sicklebar mowers cut more cleanly but leave the stalks whole. Using a front-mounted flail chopper avoids the problem of skips where tractor tires flatten the plants, putting them out of reach of a rear-mounted chopper.

Any operations that decrease the residue size shortens the period during which the decomposing residue will tie up soil nitrogen and hinder early planted crops in spring. Even when mowed, residue will become tough and slower to break down if left on the surface.

Flail chopping after frost or killing the cover crop with herbicide will create a suitable mulch for no-till planting, preserving soil life and soil structure in non-compacted fields.

Pest Management

Weeds. Use sorghum-sudangrass to help control nutsedge infestations, suggests Cornell Extension IPM vegetable specialist John Mishanec. Allow the nutsedge to grow until it's about 4 to 5 inches tall but before nutlets form, about mid-June in New York. Kill the nutsedge with herbicide, then plant the weed-smothering hybrid.

To extend weed suppressive effects into the second season, select a cultivar known for weed suppression and leave roots undisturbed when the stalks are mowed or grazed (440).

Beneficial habitat. Some related sorghum cultivars harbor beneficial insects such as seven-spotted lady beetles (*Coccinella septempunctata*) and lacewings (*Chrysopa carnea*) (421).

Nematodes. Sorghum-sudangrass hybrids and other sorghum-related crops and cultivars suppress some species of nematodes. Specific cultivars vary in their effectiveness on different races of nematodes. These high-biomass-producing crops have a general suppressive effect due to their organic matter contributions. But they also produce natural nematicidal compounds that chemically suppress some nematodes, many studies show.

Timing of cutting and tillage is very important to the effectiveness of nematode suppression. The cover crop needs to be tilled before frost while it is still green. Otherwise, the nematicidal effect is lost. For maximum suppression of soilborne diseases, cut or chopped sudangrass must be well incorporated immediately (308).

For suppressing root-knot nematodes in Idaho potato fields, rapeseed has proven slightly more effective and more dependable than sorghum-sudangrass hybrids (394).

In an Oregon potato trial, TRUDAN 8 sudangrass controlled Columbia root-knot nematodes (*Meloidogoyne Chitwoodi*), a serious pest of many vegetable crops. Control extended throughout the zone of residue incorporation. The cover crop's effect prevented upward migration of the nematodes into the zone for six weeks, working as well as the nematicide ethoprop. Both treatments allowed infection later in the season (285).

In the study, TRUDAN 8 sudangrass and the sorghum-sudangrass hybrid cultivars SORDAN 79 and SS-222 all reduced populations of root-knot nematodes. These cultivars are poor nematode hosts and their leaves—not roots—have a nematicidal effect. TRUDAN 8 should be used if the crop will be grazed due to its lower potential for prussic acid poisoning. The sorghum-sudangrass cultivars are useful if the cover crop is intended for anti-nematicidal effects only (285). In other Oregon and Washington trials, the cover crop suppression required supplemental chemical nematicide to produce profitable levels of U.S. No. 1 potatoes (285). These same sudangrass and

sorghum-sudangrass hybrid cultivars failed to show any significant nematicidal effects in a later experiment in Wisconsin potato fields (249).

When faced with infestations of the nematodes *Meloidogoyne incognita* and *M. arenaria*, Oswego, N.Y., onion grower Dan Dunsmoor found that a well-incorporated sorghum-sudangrass cover crop was more effective than fumigation. Further, the nematicidal effect continued into the next season, while the conditions a year after fumigation seemed worse than before the application. He reports that the sorghum-sudangrass cover crop also controls onion maggot, thrips and Botrytis leaf blight (217).

These plants produce chemicals that inhibit certain weeds and nematodes.

Insect pests. Chinch bug (*Blissus leucopterus*), sorghum midge (*Contarinia sorghicola*), corn leaf aphid (*Rhopalosiphum maidis*), corn earworm (*Heliothis zea*), greenbugs (*Schizaphis graminum*) and sorghum webworm (*Celama sorghiella*) sometimes attack sorghum-sudangrass hybrids. Early planting helps control the first two pests, and may reduce damage from webworms. Some cultivars and hybrids are resistant to chinch bugs and some biotypes of greenbugs (361). In Georgia, some hybrids hosted corn leaf aphid, greenbug, southern green stinkbugs (*Nezara viridula*) and leaffooted bug (*Leptoglossus phyllopus*).

Crop Systems

There are several strategies for reducing nitrogen tie-up from residue:

- Interplant a legume with the sorghum-sudangrass hybrid.
- Plant a legume cover crop *after* the sorghum-sudangrass hybrid, in either late summer or the following spring.
- Apply nitrogen fertilizer or some other N source at incorporation and leave the land fallow for a few months when soil is not frozen to allow decomposition of the residue.

Summer Covers Relieve Compaction

A summer planting of sudangrass was the best single-season cover crop for relieving soil compaction in vegetable fields, a team of Cornell researchers found. Yellow mustard, HUBAM annual white sweetclover and perennial ryegrass also were effective to some extent in the multi-year study. “But sudangrass has proven the most promising so far,” says project coordinator David Wolfe. “It has shown the fastest root growth.”

“Sudangrass is best managed with one mowing during the season,” Wolfe adds. Mowing promotes tillering and a deep, penetrating root system. Mowing also makes it easier to incorporate the large amount of biomass produced by this crop. With its high C:N ratio, it adds to soil organic matter.

Farmers and researchers have long known that alfalfa’s deep root system is a great compaction-buster. But alfalfa does not establish easily on wet compacted fields, and most vegetable growers can’t afford to remove land from production for two to three years to grow it, notes Wolfe. Many also lack the equipment to subsoil their fields, which is often only a temporary solution, at best. That’s why Wolfe geared his study to identify cover crops that can produce results in a single season. In the case of heat-loving sudangrass, it also may be possible to squeeze a spring or

fall cash crop into the rotation while still growing the cover during summer.

Heavy equipment, frequent tillage and lack of organic matter contribute to compaction problems for vegetable growers in the Northeast, where frequent rains often force growers into the fields when soils are wet. Compacted soils slow root development, hinder nutrient uptake, stunt plants, delay maturity and can worsen pest and disease problems (451). For example, the Cornell researchers found that slow-growing cabbages direct-seeded into compacted soils were vulnerable to flea beetle infestations (450).

Brassica cover crops such as yellow mustard were solid challengers to sudangrass as a compaction reliever, but it was sometimes difficult to establish these crops in the test. “We still have a lot to learn about how best to grow brassicas and fit them into rotations with vegetables,” Wolfe says.

Wolfe and his team assessed the cover crops’ effectiveness by measuring yields of subsequent crops and conducting a host of soil quality measurements, including infiltration rates, water-holding capacity, aggregate stability and organic matter levels.

For more information, contact David Wolfe, 607-255-7888; dww5@cornell.edu.

Updated in 2007 by Andy Clark

If you kill the cover crop early enough in fall, the residue will partially break down before cold temperatures slow biological action (361). Where possible, use sorghum-sudangrass ahead of later-planted crops to allow more time in spring for residue to decompose.

Planting sorghum-sudangrass every third year on New York potato and onion farms will rejuvenate soil, suppress weeds and may suppress soil pathogens and nematodes. Working a legume into the rotation will further build soil health and add nitrogen. Sorghum-sudangrass hybrids can pro-

vide needed soil structure benefits wherever intensive systems cause compaction and loss of soil organic matter reserves. See *Summer Covers Relieve Compaction*, above.

Grown as a summer cover crop that is cut once and then suppressed or killed, sorghum-sudangrass can reduce weeds in fall-planted alfalfa. Sorghum-sudangrass suppressed alfalfa root growth significantly in a Virginia greenhouse study (144), but no effect was observed on alfalfa germination when alfalfa was no-till planted into killed or living sorghum-sudangrass (145).

In Colorado, sorghum-sudangrass increased irrigated potato tuber quality and total marketable yield compared. It also increased nutrient uptake efficiency on the sandy, high pH soils. In this system, the sorghum-sudangrass is grown with limited irrigation, but with enough water so that the biomass could be harvested for hay or incorporated as green manure (112, 113).

In California, some table grape growers use sorghum-sudangrass to add organic matter and to reduce the reflection of light and heat from the soil, reducing sunburn to the grapes.

COMPARATIVE NOTES

Sorghum-sudangrass hybrids can produce more organic matter per acre, and at a lower seed cost, than any major cover crop grown in the U.S.

Incorporated sorghum-sudangrass residue reduces N availability to young crops more than oat residue but less than wheat residue (389).

Cultivars. When comparing sorghum-sudangrass cultivars, consider traits such as biomass yield potential, tillering and regrowth ability, disease resistance, insect resistance (especially if greenbugs are a problem) and tolerance to iron deficiency chlorosis.

If you plan to graze the cover crop, select sorghum-sudangrass hybrids and related crops with lower levels of dhurrin, the compound responsible for prussic acid poisoning. For maximum weed control, choose types high in sorgoleone, the root exudate that suppresses weeds. Sterile cultivars are best where escapes could be a problem, especially where crossing with johnsongrass (*Sorghum halpense*) is possible.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

WINTER WHEAT

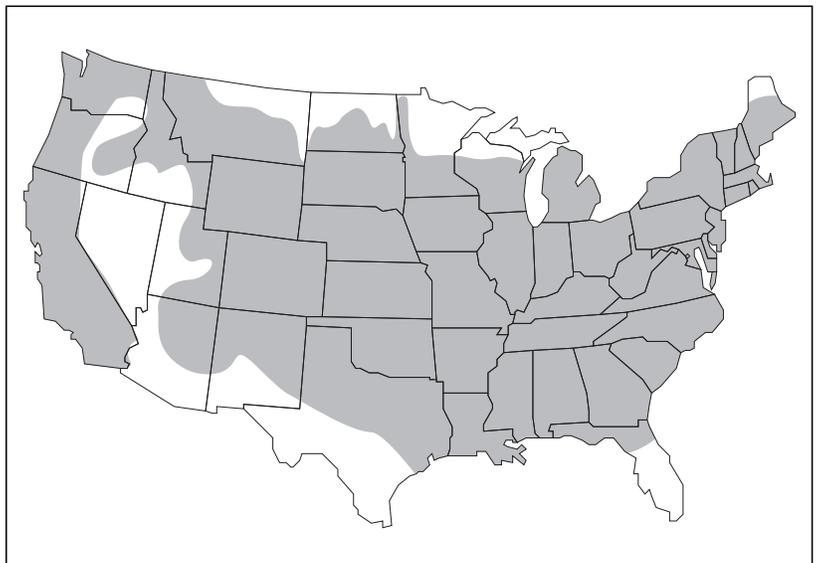
Triticum aestivum

Type: winter annual cereal grain; can be spring-planted

Roles: prevent erosion, suppress weeds, scavenge excess nutrients, add organic matter

Mix with: annual legumes, ryegrass or other small grains

See charts, pp. 66 to 72, for ranking and management summary.



Although typically grown as a cash grain, winter wheat can provide most of the cover crop benefits of other cereal crops, as well as a grazing option prior to spring tiller elongation. It's less likely than barley or rye to become a weed and is easier to kill. Wheat also is slower to mature than some cereals, so there is no

rush to kill it early in spring and risk compacting soil in wet conditions. It is increasingly grown instead of rye because it is cheaper and easier to manage in spring.

Whether grown as a cover crop or for grain, winter wheat adds rotation options for underseeding a legume (such as red clover or

OVERVIEW OF LEGUME COVER CROPS

Commonly used legume cover crops include:

- Winter annuals, such as crimson clover, hairy vetch, field peas, subterranean clover and many others
- Perennials like red clover, white clover and some medics
- Biennials such as sweetclover
- Summer annuals (in colder climates, the winter annuals are often grown in the summer)

Legume cover crops are used to:

- Fix atmospheric nitrogen (N) for use by subsequent crops
- Reduce or prevent erosion
- Produce biomass and add organic matter to the soil
- Attract beneficial insects

Legumes vary widely in their ability to prevent erosion, suppress weeds and add organic matter to the soil. In general, legume cover crops do not scavenge N as well as grasses. If you need a cover crop to take up excess nutrients after manure or fertilizer applications, a grass, a brassica or a mixture is usually a better choice.

Winter-annual legumes, while established in the fall, usually produce most of their biomass and N in spring. Winter-annual legumes must be planted earlier than cereal crops in order to survive the winter in many regions. Depending on your climate, spring management of legumes will often involve balancing early planting of the cash crop with waiting to allow more biomass and N production by the legume.

Perennial or biennial legumes can fit many different niches, as described in greater detail in the individual sections for those cover crops. Sometimes grown for a short period between

cash crops, these forage crops also can be used for more than one year and often are harvested for feed during this time. They can be established along with—or overseeded into—other crops such as wheat or oats, then be left to grow after cash crop harvest and used as a forage. Here they are functioning more as a rotation crop than a cover crop, but as such provide many benefits including erosion and weed control, organic matter and N production. They also can break weed, disease and insect cycles.

Summer-annual use of legume crops includes, in colder climates, the use of the winter-annual crops listed above, as well as warm-season legumes such as cowpeas. Grown as summer annuals, these crops produce N and provide ground cover for weed and erosion control, as well as other benefits of growing cover crops. Establishment and management varies widely depending on climate, cropping system and the legume itself. These topics will be covered in the individual sections for each legume.

Legumes are generally lower in carbon and higher in nitrogen than grasses. This lower C:N ratio results in faster breakdown of legume residues. Therefore, the N and other nutrients contained in legume residues are usually released faster than from grasses. Weed control by legume residues may not last as long as for an equivalent amount of grass residue. Legumes do not increase soil organic matter as much as grasses.

Mixtures of legume and grass cover crops combine the benefits of both, including biomass production, N scavenging and additions to the system, as well as weed and erosion control. Some cover crop mixtures are described in the individual cover crop sections. 🌱

CRIMSON CLOVER

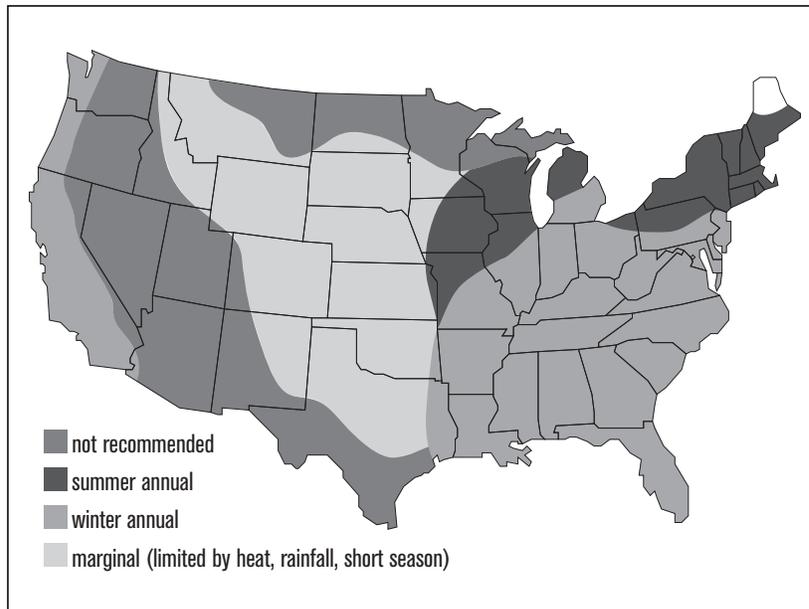
Trifolium incarnatum

Type: winter annual or summer annual legume

Roles: N source, soil builder, erosion prevention, reseeding inter-row ground cover, forage

Mix with: rye and other cereals, vetches, annual ryegrass, subclover, red clover, black medic

See charts, p. 66 to 72, for ranking and management summary.



With its rapid, robust growth, crimson clover provides early spring nitrogen for full-season crops. Rapid fall growth, or summer growth in cool areas, also makes it a top choice for short-rotation niches as a weed-suppressing green manure. Popular as a staple forage and roadside cover crop throughout the Southeast, crimson clover is gaining increased recognition as a versatile summer-annual cover in colder regions. Its spectacular beauty when flowering keeps it visible even in a mix with other flowering legumes, a common use in California nut groves and orchards. In Michigan, it is used successfully between rows of blueberries.

BENEFITS

Nitrogen source. Whether you use it as a spring or fall N source or capitalize on its vigorous reseeding ability depends on your location. Growers in the “crimson clover zone”—east of the Mississippi, from southern Pennsylvania and southern Illinois south—choose winter annual crimson clover to provide a strong, early N boost. In Hardiness Zone 8—the warmer half of the Southeast—crimson clover will overwinter dependably with only infrequent winterkill. Its N contribution is 70 to 150 lb./A.

Reseeding cultivars provide natural fertility to corn and cotton. Crimson clover works especially well before grain sorghum, which is planted later than corn. It is being tested extensively in no-till and zone-till systems. One goal is to let the legume reseed yearly for no-cost, season-long erosion control, weed suppression and nitrogen banking for the next year.

Along the northern edge of the “crimson clover zone,” winterkill and fungal diseases will be more of a problem. Hairy vetch is the less risky overwintering winter annual legume, here and in northern areas. Crimson clover often can survive winters throughout the lower reaches of Zone 6, especially from southeastern Pennsylvania northeast to coastal New England (195).

Crimson clover is gaining popularity as a winter-killed annual, like oats, in Zones 5 and colder. Planted in late summer, it provides good ground-cover and weed control as it fixes nitrogen from the atmosphere and scavenges nitrogen from the soil. Its winterkilled residue is easy to manage in spring.

Biomass. As a winter annual, crimson clover can produce 3,500 to 5,500 lb. dry matter/A and fix 70 to 150 lb. N/A by mid-May in Zone 8 (the inland Deep South). In a Mississippi study, crimson clover

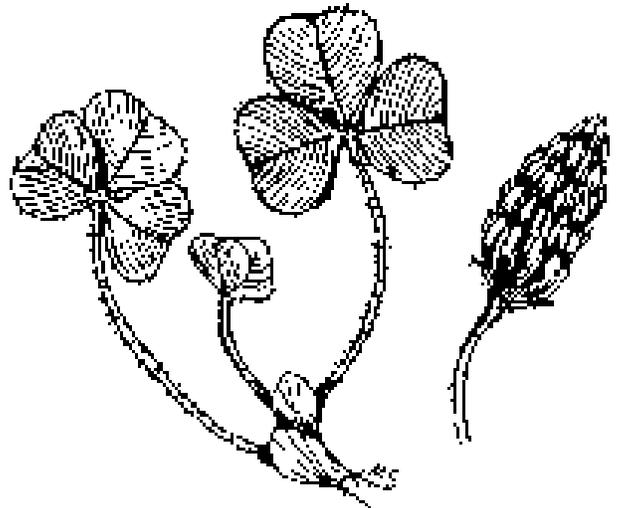
had produced mature seed by April 21, as well as 5,500 lb. DM and 135 lb. N/A. The study concluded that crimson clover is one of several winter annual legumes that can provide adequate but not excessive amounts of N for southern grain sorghum production (22, 36, 105). Crimson clover has produced more than 7,000 lb. DM/A several times at a USDA-ARS site in Beltsville, Md., where it produced 180 lb. N and 7,800 lb. DM/A in 1996 (412).

In field trials of six annual legumes in Mississippi, crimson clover was found to produce the most dry matter (5,600 to 6,000 lb./A) compared to hairy vetch, bigflower vetch, berseem clover, arrowleaf clover (*Trifolium vesiculosum*) and winter peas. It produced 99 to 130 lb. N/A and is recommended for soil erosion control because of its high early-autumn dry matter production (426).

As a summer annual in lower Michigan, a mid-summer planting of crimson clover seeded at 20 lb./A produced 1,500–2,000 lb. dry matter and 50–60 lb. N/A by late November (270).

Mixtures. Crimson clover grows well in mixtures with small grains, grasses and other clovers. An oats crop is a frequent companion, either as a nurse crop to establish a clear stand of crimson clover, or as a high-biomass, nutrient-scavenging partner. In California, crimson clover is planted with rose clover and medics in orchards and nut groves to minimize erosion and provide some N to tree crops (422).

Beneficial habitat and nectar source. Crimson clover has showy, deep red blossoms 1/2 to 1 inch long. They produce abundant nectar, and are visited frequently by various types of bees. The blooms may contain many minute pirate bugs, an important beneficial insect that preys on many small pests, especially thrips (422). In Michigan, crimson increased blueberry pollination when planted in row middles. Georgia research shows that crimson clover sustains populations of pea aphids and blue alfalfa aphids. These species are not pests of pecans, but provide alternative food for beneficial predators such as lady beetles, which later attack pecan aphids.



Marianne Sarrantonio

CRIMSON CLOVER (*Trifolium incarnatum*)

Nutrient cycler. Crimson clover adds to the soil organic N pool by scavenging mineralized N and by normal legume N fixation. The scavenging process, accomplished most effectively by grasses, helps reduce the potential for N leaching into groundwater during winter and spring (181, 265). Mixed with annual ryegrass in a simulated rainfall study, crimson clover reduced runoff from the herbicide lactofen by 94 percent and norflurazon and fluometuron by 100 percent (346). The grass/legume mixture combines fibrous surface roots with short tap roots.

MANAGEMENT

Establishment & Fieldwork

Crimson clover will grow well in about any type of well drained soil, especially sandy loam. It may fare poorly on heavy clay, waterlogged, extremely acid or alkaline soils. Once established, it thrives in cool, moist conditions. Dry soil often hinders fall plantings in the South.

Inoculate crimson clover if it hasn't been grown before. Research in Alabama showed that deficiencies of phosphorus or potassium—or strongly acidic soil with a pH of less than 5.0—can virtually shut down N fixation. Nodules were not even formed at pH 5.0 in the test. Phosphorus deficiency causes many small but inactive nodules to form (188).

Winter annual use. Seed six to eight weeks before the average date of first frost at 15 to 18 lb./A drilled, 22 to 30 lb./A broadcast. As with other winter legumes, the ideal date varies with elevation. In North Carolina, for example, the recommended seeding dates are three weeks later along the coast than in the mountains.

Don't plant too early or crimson clover will go to seed in the fall and not regrow in spring until

**In Hardiness
Zone 5 and
colder, crimson
clover can
provide a
winterkilled
mulch.**

the soil warms up enough to germinate seeds. Early to mid-August seeding is common in the northern part of crimson clover's winter-annual range. In southern Michigan (Zone 5b - 6a) crimson clover, no-tilled into wheat stubble in mid-July, not only grew well into fall, but thrived the following spring, performing nearly as well as hairy vetch (270).

While October plantings are possible in the lower Mississippi Delta, an August 15 planting in a northern Mississippi test led to higher yields than later dates (228). In the lower Coastal Plain of the Gulf South, crimson clover can be planted until mid-November.

Nutrient release from crimson clover residue—and that of other winter annual legumes—is quicker if the cover crop is tilled lightly into the soil. Apart from erosion concerns, this fertility enhancing step adds cost and decreases the weed-suppression effect early in the subsequent crop's cycle.

Summer annual use. In general, plant as soon as all danger of frost is past. Spring sowing establishes crimson clover for a rotation with potatoes in Maine. In Michigan, researchers have successfully established crimson clover after short-season crops such as snap beans (229, 270).

In Northern corn fields, Michigan studies showed that crimson clover can be overseeded at final cultivation (layby) when corn is 16 to 24 inches tall. Crimson clover was overseeded at 15 lb./A in 20-inch bands between 30-inch rows

using insecticide boxes and an air seeder. The clover established well and caused no corn yield loss (295). Crimson clover has proved to be more promising in this niche than black medic, red clover or annual ryegrass, averaging 1,500 lb. DM/A and more than 50 lb. N/A (270).

In Maine, spring-seeded crimson clover can yield 4,000 to 5,000 lb. DM/A by July, adding 80 lb. N/A for fall vegetables. Mid-July seedings have yielded 5,500 lb./A of weed-suppressing biomass by late October. Summer-annual use is planned with the expectation of winterkill. It sometimes survives the winter even in southern Michigan (270), however, so northern experimenters should maintain a spring-kill option if icy winds and heaving don't do the job.

In California, spring sowing often results in stunting, poor flowering and reduced seed yield, and usually requires irrigation (422).

Rotations. In the South, crops harvested in early fall or sown in late spring are ideal in sequence with crimson clover. Timely planting of crimson clover and its rapid spring growth can enable it to achieve its maximum N contribution, and perhaps reseed. While corn's early planting date and cotton's late harvest limit a traditional winter-annual role for crimson clover, strip planting and zone tillage create new niches. By leaving unkilld strips of crimson clover to mature between zone-tilled crop rows, the legume sets seed in May. The majority of its hard seed will germinate in fall.

Kill crimson clover before seed set and use longer season cultivars where regrowth from hard seed would cause a weed problem.

Researchers have successfully strip-tilled into standing crimson clover when 25 to 80 percent of the row width is desiccated with a herbicide or mechanically tilled for the planting area. Narrower strips of crimson clover increased weed pressure but reduced moisture competition, while wider strips favored reseeding of the cover (236).

In a crimson clover-before-corn system, growers can optimize grain yields by no-tilling into the crimson clover and leaving the residue on the surface, or optimize total forage yield by harvesting the crimson clover immediately before planting

corn for grain or silage (204). In Mississippi, sweet potatoes and peanuts suffered no yield or quality penalty when they were no-tilled into killed crimson clover. The system reduced soil erosion and decreased weed competition (35).

In Ohio, crimson clover mixed with hairy vetch, rye and barley provided a fertility enhancing mulch for no-till processing tomato transplants. Use of a prototype undercutter implement with a rolling harrow provided a good kill. Because the wide blades cut just under the soil surface on raised beds, they do not break stalks, thus lengthening residue durability. The long-lasting residue gave excellent results, even under organic management without the herbicides, insecticides or fungicides used on parallel plots under different management regimes. Nancy Creamer at the University of North Carolina is continuing work on the undercutter and on cover crops in organic vegetable systems (96).

Mixed seeding. For cover crop mixtures, sow crimson clover at about two-thirds of its normal rate and the other crop at one third to one-half of its monoculture rate. Crimson clover development is similar to tall fescue. It even can be established with light incorporation in existing stands of aggressive grasses after they have been closely mowed or grazed.

Reseeding. Overwintered crimson clover needs sufficient moisture at least throughout April to produce seed (130). Cultivar selection is critical when early spring maturity is needed.

DIXIE and CHIEF are full-season standards. AU ROBIN and FLAME beat them by about two weeks; a new cultivar, AU SUNRISE, is reportedly 1-3 weeks earlier; the popular TIBBEE is about a week ahead of the standards. Price varies more by seasonal supply than by cultivar.

Killing. Its simple taproot makes crimson clover easy to kill mechanically. Mowing after early bud stage will kill crimson clover. Maximum N is available at late bloom or early seed set, even before the plant dies naturally. Killing earlier yields less N—up to 50 lb. N/A less at its late vegetative stage, which is about 30 days before early seed set (342).

A rolling stalk chopper flattens a mix of crimson clover, hairy vetch and rye ahead of no-till vegetable transplanting at Steve Groff's farm in southeastern Pennsylvania. The crimson is killed completely if it is in full bloom; and even early bloom is killed better than vegetative crimson.

Pest Management

Crimson clover is a secondary host to plant pests of the *Heliothis* species, which include corn earworm and cotton bollworm. Despite its known benefits, crimson clover has been eradicated from many miles of roadsides in Mississippi at the request of some Delta farmers who suspect it worsens problems from those pests (106).

Crimson clover doesn't significantly increase risk of Southern corn rootworm in no-till corn, while hairy vetch does (67). It is more resistant to diseases (422) and to some nematodes than other clovers (337). Crimson clover is said to tolerate viral diseases, but it succumbed to virus in July plantings in Mississippi (228) and to *Sclerotinia* in fall plantings in Maryland (108).

In lab tests, crimson clover, berseem clover and hairy vetch have been shown to inhibit germination and seedling development of onion, carrot and tomato (40). However, this interference hasn't been observed in North Carolina field crops where strips are mechanically tilled, or in other studies with crimson clover as part of a killed organic mulch. No-till vegetable transplanting has been done successfully on the same day as mechanically killing the cover crop mix on Steve Groff's Lancaster County, Pa., farm with no negative effects.

Wait two to three weeks after killing before planting seeds, to allow the biomass to begin to decompose and the soil biological life to stabilize. During this time, a flush of bacteria such as *Pythium* and *Rhizoctonia* attack rapidly decaying plants. These bacteria also can attack seedling crops. To plant more quickly, mow the clover and

**In Mississippi,
crimson clover
produced mature
seed and 135 lb.
N/A by April 21.**

use row cleaners to clear the tops from the seed zone. The mow/wait/plant cycle also may be influenced by the need to wait for rain to increase seedbed moisture.

Mixed with hairy vetch, crimson clover attracts beneficial insects, provides nitrogen and suppresses weeds in Oklahoma's native and plantation pecan groves. Both legumes go to seed and then are harvested for forage. Arrowleaf clover provided more biomass and N, but didn't work as well for insect pest management and is very susceptible to root knot nematode.

Crimson clover harbors flower thrips and is a more likely host for tarnished plant bug than hairy vetch or subterranean clover (56). Intensive screenings show less abundant arthropod herbivores and predators on crimson clover than on hairy vetch (206).

Tillage practices and residue management variations (no-till, incorporate, removal) of cover cropped lupin, rye, hairy vetch or crimson clover had little consistent effect on nematodes in north Florida corn fields (264).

Other Options

Pasture and hay crop. Crimson clover is excellent for grazing and haying. It will regrow if grazed or mowed no lower than 3 or 4 inches before the

early bud stage. Mixing with grass reduces its relatively low bloat risk even further. Timely mowing four to six weeks before bloom improves growth, reduces lodging and will cause more uniform flowering and seed ripening on highly fertile soils (120, 422).

Crimson clover can be grazed lightly in the fall, more intensively in the spring and still be left to accumulate N and/or set seed with little reduction in its soil N contribution, provided livestock are removed before flowering (80).

COMPARATIVE NOTES

Crimson clover is:

- less tolerant of mowing than are subclovers or medics (422)
- similar to hairy vetch and Austrian winter pea in the Southeast for total N production
- a better weed suppressor in fall than hairy vetch
- earlier to mature in spring than hairy vetch

Cultivars. See *Reseeding* (p. 154) for cultivar comparisons.

Seed Sources. See *Seed Suppliers* (p. 195). 🌱

much long-term organic matter. Peas do not make a good organic mulch for weed control (361).

Nitrogen source. Austrian winter peas are top N producers, yielding from 90 to 150 lb. N/A, and at times up to 300 lb. N/A.

Plowed down as green manure, fall-planted legume crops of Austrian winter pea, alfalfa and hairy vetch each produced enough N for the production of high-quality muskmelons under plastic mulch and drip irrigation in a Kansas study. Melon yields produced with the legumes were similar to those receiving synthetic fertilizer at 63 and 90 lb. N/A. The winter peas in the experiment produced 96 lb. N/A the first year and 207 lb. N/A the second (387).

Austrian winter peas harvested as hay then applied as mulch mineralized N at more than double the rate of alfalfa hay. The N contribution was measured the summer after a fall plowdown of the residue. The estimated N recovery of Austrian winter pea material 10 months after incorporation was 77 percent—58 percent through spring wheat and 19 percent in the soil (254).

Austrian winter pea green manure provided the highest spring wheat yield the following year in a Montana trial comparing 10 types of medics, seven clovers, yellow biennial sweet clover and three grains. Crops that produced higher tonnage of green manure usually had a negative effect on the subsequent wheat crop due to moisture deficiency that continued over the winter between the crops (381). Field peas can leave 80 lb. N/A if terminated at mid-season in lieu of summer fallow in dryland areas, or leave more than 30 lb. N/A after pea harvest at season's end (74).

A winter pea green manure consistently resulted in higher malting barley protein content than that following other legumes or fallow in a Montana trial. Annual legumes harvested for seed left less soil N than did plots in fallow. Also tested were fava bean, lentil, chickpea, spring pea, winter pea hay and dry bean (262).

Rotational effects. Pulse crops (grain legumes such as field peas, fava beans and lentils) improved sustainability of dryland crop rotations by pro-

viding disease suppression, better tillth and other enhancements to soil quality in a Saskatchewan study. Even at rates of 180 lb. N/A, fertilizer alone was unable to bring yields of barley planted into barley residue to the maximum achieved from these pulse residues (163).

Water thrifty. In a comparison of water use alongside INDIANHEAD lentils and GEORGE black medic, Austrian winter pea was the most moisture-efficient crop in producing biomass. Each crop had used 4 inches of water when Austrian winter pea vines were 16 inches long, the lentils were 6 to 8 inches tall and the black medic central tillers were 4 inches tall (383).

Austrian winter peas grown in a controlled setting at 50° F recorded more than 75 percent of its N₂ fixed per unit of water used by the 63rd day of growth. White clover, crimson clover and hairy vetch reached the same level of water efficiency, but it took 105 days (334).

Quick growing. Rapid spring growth helps peas out compete weeds and make an N contribution in time for summer cash crops in some areas.

Forage booster. Field peas grown with barley, oat, triticale or wheat provide excellent livestock forage. Peas slightly improve forage yield, but significantly boost protein and relative feed value of small grain hay.

Seed crop. Seed production in Montana is about 2,000 lb./A and about 1,500 lb./A in the Pacific Northwest. Demand is growing for field peas as food and livestock feed (74).

Long-term bloomer. The purple and white blossoms of field peas are an early and extended source of nectar for honeybees.

Chill tolerant. Austrian winter pea plants may lose some of their topgrowth during freezes, but can continue growing after temperatures fall as low as 10° F. Their shallow roots and succulent stems limit their overwintering ability, however. Sustained cold below 18° F without snow cover

usually kills Austrian winter pea (202). To maximize winter survival:

- Select the most winter-hardy cultivars available—GRANGER, MELROSE and COMMON WINTER.
- Seed early enough so that plants are 6 to 8 inches tall before soil freezes, because peas are shallow rooted and susceptible to heaving. Try to plant from mid-August to mid-September in Zone 5.
- Plant into grain stubble or a rough seedbed, or interseed into a winter grain. These environments protect young pea roots by suppressing soil heaving during freezing and thawing. Trapped snow insulates plants, as well.

MANAGEMENT

Establishment & Fieldwork

Peas prefer well-limed, well-drained clay or heavy loam soils, near-neutral pH or above and moderate fertility. They also do well on loamy sands in North Carolina. Field peas usually are drilled 1 to 3 inches deep to ensure contact with moist soil and good anchoring for plants.

If you broadcast peas, incorporation will greatly improve stands, as seed left exposed on the surface generally does not germinate well. Long-vined plants that are shallow-seeded at low seeding rates tend to fall over (lodge), lay against the soil and rot. Combat this tendency by planting with a small grain nurse crop such as oats, wheat, barley, rye or triticale. Reduce the pea seeding rate by about one quarter—and grain by about one third—when planting a pea/grain mix.

Planted at 60 to 80 lb./A in Minnesota, Austrian winter peas make a good nurse crop for alfalfa.

Field pea seed has a short shelf life compared with other crops. Run a germination test if seed is more than two years old and adjust seeding rate accordingly. If you haven't grown peas in the seeded area for several years, inoculate immediately before seeding.

West. In mild winter areas of California and Idaho, fall-plant for maximum yield. In those areas, you can expect *spring-planted* winter peas to produce about half the biomass as those that are



Marianne Sarrantonio

FIELD PEAS (*Pisum sativum* subsp. *arvense*)

fall-planted. Seed by September 15 in Zone 5 of the Inter-Mountain region in protected valleys where you'd expect mild winter weather and good, long-term snow cover. October-planted Austrian winter pea in the Zone 9 Sacramento Valley of California thrive on cool, moist conditions and can contribute 150 lb. N/A by early April.

The general rule for other parts of the semi-arid West where snow cover is dependable is to plant peas in the fall after grain harvest. In these dry regions of Montana and Idaho, overseed peas at 90 to 100 lb./A by "frostseeding" any time soils have become too cold for pea germination. Be sure residue cover is not too dense to allow seed to work into the soil through freeze/thaw cycles as the soil warms (383).

In the low-rainfall Northern Plains, broadcast clear stands of peas in early spring at a similar rate for the "Flexible Green Manure" cropping system (below). Seeding at about 100 lb./A compensates somewhat for the lack of incorporation and provides strong early competition with weeds (383). Plant as soon as soil in the top inch reaches 40° F to make the most of spring moisture (74).

A mixture of Austrian winter peas and a small grain is suitable for dryland forage production because it traps snow and uses spring moisture to produce high yields earlier than spring-seeded annual forages (74). With sufficient moisture, spring peas typically produce higher forage yields than Austrian winter peas.

East. Planted as a companion crop in early spring in the Northeast, Austrian winter peas may provide appreciable N for summer crops by Memorial Day (361). In the mid-Atlantic, Austrian winter peas and hairy vetch planted October 1 and killed May 1 produced about the same total N and corn yields (108).

Southeast. Seed by October 1 in the inland Zone 8 areas of the South so that root crowns can become established to resist heaving. Peas produce more biomass in the cooler areas of the South than where temperatures rise quickly in spring (74, 361). Peas planted in late October in South Carolina's Zone 8 and terminated in mid- to late April produce 2,700 to 4,000 lb. dry matter/A (23).

Killing

Peas are easily killed any time with herbicides, or by disking or mowing after full bloom, the stage of maturity that provides the optimum N contribution. Disk lightly to preserve the tender residue for some short-term erosion control.

**Winter pea
residue breaks
down and
releases N
quickly.**

The downside to the quick breakdown of pea vines is their slimy condition in spring if they winterkill, especially in dense, pure stands. Planting with a winter grain provides some protection from winterkill and reduces matting of dead pea vegetation.

Pest Management

Winter peas break crop disease cycles, Ben Burkett of Petal, Miss., has found. *Septoria* leaf spot problems on his cash crops are reduced when he plants Austrian winter pea in fall after snap beans and ahead of collards and mustard greens the next summer. Between October 15 and November 15, Burkett broadcasts just 50 lb./A then incorporates the seed with a shallow pass of his field cultivator. They grow 3 to 6 inches tall before going dormant in late December in his Zone 8 location about 75 miles north of the Gulf

of Mexico. Quick regrowth starts about the third week in January. He kills them in mid-April by disking, then shallow plows to incorporate the heavy residue (202).

Farmers and researchers note several IPM cautions, because Austrian winter peas:

- Host some races of nematodes
- Are susceptible to winter *Sclerotinia* crown rot, *Fusarium* root rot as well as seed rot and blights of the stem, leaf or pod
- Are variably susceptible to the *Ascochyta* blight (MELROSE cultivar has some resistance)
- Host the pathogen *Sclerotinia* minor. There was a higher incidence of leaf drop in California lettuce planted after Austrian winter peas in one year of a two-year test (232).

Austrian winter peas were heavily damaged by *Sclerotinia trifoliorum* Eriks in several years of a four-year study in Maryland, but the crop still produced from 2,600 to 5,000 lb. dry matter/A per year in four out of five years. One year DM production was only 730 lb./A. Mean N contribution despite the disease was 134 lb. N/A. Overall, Austrian winter peas were rated as being more suited for Maryland Coastal Plain use than in the Piedmont, due to harsher winters in the latter location (204).

To combat disease, rotate cover crops to avoid growing peas in the same field in successive years. To minimize disease risk, waiting several years is best. To minimize risk of losing cover crop benefits to *Sclerotinia* disease in any given season, mix with another cover crop such as cereal rye.

Crop Systems

Northern Plains. Austrian winter peas (and other grain legumes) are increasingly used instead of fallow in dryland cereal rotations. The legumes help prevent saline seeps by using excess soil moisture between cereal crops. They also add N to the system. The legume>cereal sequence starts with a spring- or fall-planted grain legume (instead of fallow), followed by a small grain.

Peas work well in this system because they are shallow-rooted and therefore do not extract deep soil moisture. The pea crop is managed according

to soil moisture conditions. Depending on growing season precipitation, the peas can be grazed, terminated or grown to grain harvest. Growers terminate the crop when about 4 inches of plant-available water remains in the soil, as follows:

- **Below-normal rainfall**—terminate the grain legume early.
- **Adequate rainfall**—terminate the grain legume when about 4 inches of soil water remains. Residue is maintained for green manure, moisture retention and erosion prevention.
- **Above-average rainfall**—grow the crop to maturity for grain harvest.

In conventional fallow systems, fields are left unplanted to accumulate soil moisture for the cash crop. Weeds are controlled using tillage or herbicides.

Grain legumes provide a soil-protecting alternative to fallow that can be managed to ensure adequate moisture for the cereal crop. Legumes provide long-term benefits by producing N for the subsequent crop, disrupting disease, insect and weed cycles and building soil.

Austrian winter peas work in these rotations where there is at least 18 inches of rain per year. INDIANHEAD lentils (*Lens culinaris* Medik), a specialty lentil for cover crop use, are also widely used in this system.

Montana research shows that when soil moisture is replenished by winter precipitation, annual legumes can substitute for fallow without significantly reducing the yield of the next barley crop. Montana rainfall averages 12-16 inches, so peas are planted but can only be taken to grain harvest in above-normal rainfall years. The legume can generate income from harvest of its hay or grain or through fertilizer N savings from the legume's contribution to the small grain crop (136).

In Idaho, fall-seeded Austrian winter peas harvested for seed provided income, residual N from the pea straw and soil disease suppression in a study of efficient uses of the legume cover. A crop rotation of Austrian winter pea (for grain)>winter wheat>spring barley produced similar wheat

yields as did using the peas as green manure or leaving the field fallow in the first year. While neither Austrian winter pea green manure nor fallow produced income, the green manure improved soil organic matter and added more N for wheat than did summer fallow. Fallow caused a net soil capacity loss by "mining" finite soil organic matter reserves (253).

In a northern Alberta comparison of conventional (tilled), chemical (herbicide) and green (field pea) fallow systems, spring-planted field peas provided 72 lb. N/A, significantly more than the other systems. The field pea system was also more profitable when all inputs were considered, providing higher yield for two subsequent cash crops, higher income and improvement of soil quality (12).

Southeast. Fall-seeded Austrian winter peas out-produced hairy vetch by about 18 percent in both dry matter and N production in a three-year test in the Coastal Plain of North Carolina. When legumes were grown with rye, wheat or spring oats, Austrian winter pea mixtures also had the highest dry matter yields. Over the three years, Austrian winter peas ranked the highest (dry-matter and N) in the legume-only trials and as the legume component of the legume/grain mixtures. In descending order after the peas were hairy vetch, common vetch and crimson clover. The peas were sown at 54 lb./A in the pure seedings and 41 lb./A in mixtures (344).

In the year of greatest N fixation, soil N in the Austrian winter pea mixture treatments was 50 percent greater than the average of all other treatments. Researchers noted that the bottom leaves of pea vines were more decomposed than other legumes, giving the crop an earlier start in N contribution. Further, soil N in the upper 6 inches of soil under the Austrian winter peas held 30 to 50 percent of the total soil inorganic N in the winter pea treatments, compared with levels of less than

**In the
Northeast,
spring-planted
peas can be
incorporated by
Memorial Day.**

Peas Do Double Duty for Kansas Farmer

PARTRIDGE, Kan.—Jim French figures Austrian winter peas provide free grazing, free nitrogen, or both. The vining legume produces just as much N for the following grain sorghum crop even if he lets his registered Gelbvieh herd eat all they want of the winter annual's spring growth.

French farms on flat, well-drained sandy loam soil near Partridge, Kan. He manages about 640 acres each of cash crops (winter wheat and grain sorghum) and forages (alfalfa, sudangrass, winter peas and cowpeas, and an equal area in grass pasture). Peas follow wheat in the three-year crop rotation on his south-central Kansas farm. He chisel plows the wheat stubble twice about 7 inches deep, disks once to seal the surface, then controls weeds as necessary with a light field cultivator.

Between mid-September and mid-October he inoculates about 30 lb./A of the peas and drills them with an old John Deere double-run disk drill in 8-inch rows. Establishment is usually good, with his only anxiety coming during freeze-thaw cycles in spring. "Each time the peas break dormancy, start to grow, then get zapped with cold again they lose some of their root reserves and don't have quite the resistance to freezing they did. They'll sprout back even if there's vegetative freeze damage as long as their food reserves hold out," French reports.

Ironically, this spring freezing is less of a problem further north where fields stay frozen longer before a slower thaw. This works as long as snow cover protects the peas from the

colder early and mid-winter temperatures. In most years, he sets up temporary fence and turns his cattle into the peas about April 1 at the stocking rate of two animal units per acre. During the best years of mild weather and adequate moisture, "the cattle have a hard time keeping up," says French. Depending on his need for forage or organic matter, he leaves the cattle in until he incorporates the pea stubble, or gives it time to regrow.

One reason he gets about the same 90 to 120 lb. N/A contribution with or without grazing is that the winter pea plants apparently continue N fixation and root growth while being grazed. Soil tests show that 25 to 30 lb. N/A are available in the nitrate form at incorporation in late spring, with the balance in an organic form that mineralizes over the summer. Grazing the peas helps to contain cheatgrass, which tends to tie up N if it's incorporated just ahead of his sorghum crop.

French is sold on winter peas ahead of his grain sorghum because it provides N while reducing weed pressure from cheatgrass and pigweed and decreasing lodging from charcoal root rot. The option to use the peas as forage—while still achieving adequate sorghum yield—lets him buy less processed feed, improves livestock health and accelerates conversion of the peas' organic material into available soil nutrients.

"Winter peas work best where you integrate crops and livestock," says French. "They give you so many benefits."

30 percent in the top soil layer for all other treatments. In situations where the early-summer N release from peas could be excessive, mixing Austrian winter peas with a grain can moderate the N contribution and slow down its release into the soil (344).

The carbon to nitrogen (C:N) ratio of plant matter is an indication of how rapidly vegetation will

break down. Mixtures of small grains with Austrian winter peas and the vetches had C:N values from 13 to 34, but were generally under 25 to 30, the accepted threshold for avoiding net immobilization of N (344).

Austrian winter peas and crimson clover can provide adequate N for conventionally planted cotton in South Carolina. In a three-year trial, fertilizer

rates of up to 150 lb. N/A made no improvement to cotton yield on the pea plots. The evaluation showed that soil nitrate under Austrian winter peas peaked about nine weeks after incorporation (22).

Austrian winter peas achieved 50 to 60 percent groundcover when they were overseeded at about 75 lb./A into soybeans at leaf yellowing in southeastern Pennsylvania, where they can survive some winters. The peas produced nearly 2 tons of dry matter and 130 lb. N/A by May 20 in this test (191). Overseeding peas into corn at last cultivation is not recommended due to poor shade tolerance.

Austrian winter peas, like other hollow-stemmed succulent covers such as vetch and fava beans, do not respond well to mowing or cutting after they begin to bloom. In their earlier stages, Austrian winter peas will regrow even when grazed several times. See *Peas Do Double Duty for Kansas Farmer* (p. 140).

After three years of moisture testing, Kansas farmer Jim French can explain why he sees more soil moisture after spring grazing than when the peas are left to grow undisturbed. "There's decreasing overall transpiration because there's less leaf area to move moisture out of the soil into the air. Yet the root mass is about the same." Ungrazed peas pump more water as they keep growing.

Other Options.

Harvest field peas for hay when most of the pods are well formed. Use a mower with lifting guards and a windrow attachment to handle the sprawling vines.

COMPARATIVE NOTES

Field peas won't tolerate field traffic due to succulent stems (191). When selecting types, remember that long-vined varieties are better for weed control than short-vined types.

Cultivars. MELROSE, known for its winter-hardiness, is a cultivar of the Austrian winter pea type. Planted the first week of September in Idaho, MELROSE peas yielded 300 lb. N/A and 6 tons of dry matter the next June. Planted in mid-April, the cultivar yielded "just" 175 lb. N/A and 3.5 T dry matter/A (202).

GRANGER is an improved winter pea that has fewer leaves and more tendrils, which are stiffer than standard cultivars. It is more upright and its pods dry more quickly than other winter pea types. MAGNUS field peas have out-produced Austrian winter peas in California and bloom up to 60 days earlier.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

In dryland systems, winter peas produce abundant biomass with limited moisture.

HAIRY VETCH

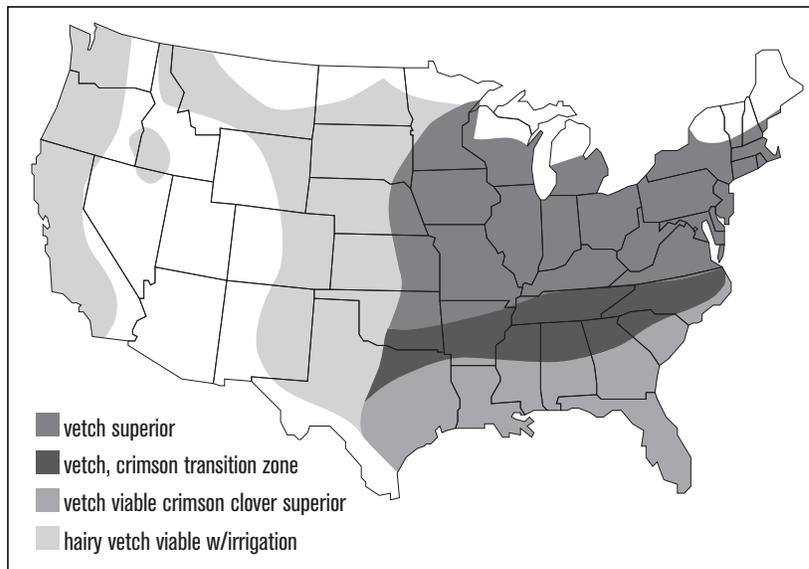
Vicia villosa

Type: winter annual or summer annual legume

Roles: N source, weed suppressor, topsoil conditioner, reduce erosion

Mix with: small grains, field peas, bell beans, crimson clover, buckwheat

See charts, p. 66 to 72, for ranking and management summary.



Few legumes match hairy vetch for spring residue production or nitrogen contribution. Widely adapted and winter hardy through Hardiness Zone 4 and into Zone 3 (with snow cover), hairy vetch is a top N provider in temperate and subtropical regions.

The cover grows slowly in fall, but root development continues over winter. Growth quickens in spring, when hairy vetch becomes a sprawling vine up to 12 feet long. Field height rarely exceeds 3 feet unless the vetch is supported by another crop. Its abundant, viney biomass can be a benefit and a challenge. The stand smothers spring weeds, however, and can help you replace all or most N fertilizer needs for late-planted crops.

BENEFITS

Nitrogen source. Hairy vetch delivers heavy contributions of mineralized N (readily available to the following cash crop). It can provide sufficient N for many vegetable crops, partially replace N fertilizer for corn or cotton and increase cash crop N efficiency for higher yield.

In some parts of California and the East in Zone 6, hairy vetch provides its maximum N by safe corn planting dates. In Zone 7 areas of the Southeast, the fit is not quite as good, but substantial N from vetch is often available before corn planting.

Corn planting date comparison trials with cover crops in Maryland show that planting *as late* as May 15 (the very end of the month-long local planting period) optimizes corn yield and profit from the system. Spring soil moisture was higher under the vetch or a vetch-rye mixture than under cereal rye or no cover crop. Killed vetch left on the surface conserved summer moisture for improved corn production (80, 82, 84, 85, 173, 243).

Even without crediting its soil-improving benefits, hairy vetch increases N response and produces enough N to pay its way in many systems. Hairy vetch without fertilizer was the preferred option for “risk-averse” no-till corn farmers in Georgia, according to calculations comparing costs, production and markets during the study. The economic risk comparison included crimson clover, wheat and winter fallow. Profit was higher, but less predictable, if 50 pounds of N were added to the vetch system (310).

Hairy vetch ahead of no-till corn was also the preferred option for risk averse farmers in a three-

Note: To roughly estimate hairy vetch N contribution in pounds per acre, cut and weigh fresh vetch top growth from a 4-foot by 4-foot area. Multiply pounds of fresh vetch by 12 to gauge available N, by 24 to find total N (377). For a more accurate estimate, see *How Much N?* (p. 22).

year Maryland study that also included fallow and winter wheat ahead of the corn. The vetch-corn system maintained its economic advantage when the cost of vetch was projected at maximum historic levels, fertilizer N price was decreased, and the herbicide cost to control future volunteer vetch was factored in (173). In a related study on the Maryland Coastal Plain, hairy vetch proved to be the most profitable fall-planted, spring desiccated legume ahead of no-till corn, compared with Austrian winter peas and crimson clover (243).

In Wisconsin's shorter growing season, hairy vetch planted after oat harvest provided a gross margin of \$153/A in an oat/legume/corn rotation (1995 data). Profit was similar to using 160 lb. N/A in continuous corn, but with savings on fertilizer and corn rootworm insecticide (400).

Hairy vetch provides yield improvements beyond those attributable to N alone. These may be due to mulching effects, soil structure improvements leading to better moisture retention and crop root development, soil biological activity and/or enhanced insect populations just below and just above the soil surface.

Soil conditioner. Hairy vetch can improve root zone water recharge over winter by reducing runoff and allowing more water to penetrate the soil profile through macropores created by the crop residue (143). Adding grasses that take up a lot of water can reduce the amount of infiltration and reduce the risk of leaching in soils with excess nutrients. Hairy vetch, especially an oats/hairy vetch mix, decreased surface ponding and soil crusting in loam and sandy loam soils. Researchers attribute this to dual cover crop benefits: their ability to enhance the stability of soil aggregates (particles), and to decrease the likelihood that the aggregates will disintegrate in water (143).

Hairy vetch improves topsoil tilth, creating a loose and friable soil structure. Vetch doesn't build up long-term soil organic matter due to its tendency to break down completely. Vetch is a succulent crop, with a relatively "low" carbon to nitrogen ratio. Its C:N ratio ranges from 8:1 to 15:1, expressed as parts of C for each part of N. Rye C:N ratios range from 25:1 to 55:1, showing why it persists much longer under similar condi-



Marianne Sarrantonio

HAIRY VETCH (Vicia villosa)

tions than does vetch. Residue with a C:N ratio of 25:1 or more tends to immobilize N. For more information, see *How Much N?* (p. 22), and the rest of that section, *Building Soil Fertility and Tillth with Cover Crops* (p. 16).

Early weed suppression. The vigorous spring growth of fall-seeded hairy vetch out-competes weeds, filling in where germination may be a bit spotty. Residue from killed hairy vetch has a weak allelopathic effect, but it smothers early weeds mostly by shading the soil. Its effectiveness wanes as it decomposes, falling off significantly after about three or four weeks. For optimal weed control with a hairy vetch mulch, select crops that form a quick canopy to compensate for the thinning mulch or use high-residue cultivators made to handle it.

Mixing rye and crimson clover with hairy vetch (seeding rates of 30, 10, and 20 lb./A, respectively) extends weed control to five or six weeks, about the same as an all-rye mulch. Even better, the mix provides a legume N boost, protects soil in fall and winter better than legumes, yet avoids the potential crop-suppressing effect of a pure rye mulch on some vegetables.

Good with grains. For greater control of winter annual weeds and longer-lasting residue, mix hairy vetch with winter cereal grains such as rye, wheat or oats.

Growing grain in a mixture with a legume not only lowers the overall C:N ratio of the combined residue compared with that of the grain, it may actually lower the C:N ratio of the small grain residue as well. This internal change causes the grain residue to break down faster, while accumulating the same levels of N as it did in a monoculture (344).

Moisture-thrifty. Hairy vetch is more drought-tolerant than other vetches. It needs a bit of moisture to establish in fall and to resume vegetative growth in spring, but relatively little over winter when above-ground growth is minimal.

Phosphorus scavenger. Hairy vetch showed higher plant phosphorus (P) concentrations than crimson clover, red clover or a crimson/ryegrass mixture in a Texas trial. Soil under hairy vetch also had the lowest level of P remaining after growers applied high amounts of poultry litter prior to vegetable crops (121).

Fits many systems. Hairy vetch is ideal ahead of early-summer planted or transplanted crops, providing N and an organic mulch. Some Zone 5 Midwestern farmers with access to low-cost seed plant vetch after winter grain harvest in mid-summer to produce whatever N it can until it winterkills or survives to regrow in spring.

Widely adapted. Its high N production, vigorous growth, tolerance of diverse soil conditions, low fertility need and winter hardiness make hairy vetch the most widely used of winter annual legumes.

MANAGEMENT

Establishment & Fieldwork

Hairy vetch can be no-tilled, drilled into a prepared seedbed or broadcast. Dry conditions often reduce germination of hairy vetch. Drill seed at 15 to 20 lb./A, broadcast 25 to 30 lb./A. Select a higher rate if you are seeding in spring, late in the fall, or into a weedy or sloped field. Irrigation will help

germination, particularly if broadcast seeded.

Plant vetch 30 to 45 days before killing frost for winter annual management; in early spring for summer growth; or in July if you want to kill or incorporate it in fall or for a winter-killed mulch.

Hairy vetch has a relatively high P and K requirement and, like all legumes, needs sufficient sulfur and prefers a pH between 6.0 and 7.0. However, it can survive through a broad pH range of 5.0 to 7.5 (120).

An Illinois farmer successfully no-tills hairy vetch in late August at 22 lb./A into closely mowed stands of fescue on former Conservation Reserve Program land (417). Using a herbicide to kill the fescue is cheaper than mowing, but it must be done about a month later when the grass is actively growing for the chemical to be effective. Vetch also can be no-tilled into soybean or corn stubble (50, 80).

In Minnesota, vetch can be interseeded into sunflower or corn at last cultivation. Sunflower should have at least 4 expanded leaves or yield will be reduced (221, 222).

Farmers in the Northeast's warmer areas plant vetch by mid-September to net 100 lb. available N/A by mid-May. Sown mid-August, an oats/hairy vetch mix can provide heavy residue (180).

Rye/hairy vetch mixtures mingle and moderate the effects of each crop. The result is a "hybrid" cover crop that takes up and holds excess soil nitrate, fixes N, stops erosion, smothers weeds in spring and on into summer if not incorporated, contributes a moderate amount of N over a longer period than vetch alone, and offsets the N limiting effects of rye (81, 83, 84, 86, 377).

Seed vetch/rye mixtures, at 15-25 lb. hairy vetch with 40-70 lb. rye/A (81, 361).

Overseeding (40 lb./A) at leaf-yellowing into soybeans can work if adequate rainfall and soil moisture are available prior to the onset of freezing weather. Overseeding into ripening corn (40 lb./A) or seeding at layby has not worked as consistently. Late overseeding into vegetables is possible, but remember that hairy vetch will not stand heavy traffic (361).

Killing

Your mode of killing hairy vetch and managing residue will depend on which of its benefits are most important to you. Incorporation of hairy vetch vegetation favors first-year N contribution, but takes significant energy and labor. Keeping vetch residue on the surface favors weed suppression, moisture retention, and insect habitat, but may reduce N contribution. However, even in no-till systems, hairy vetch consistently provides very large N input (replacing up to 100 lb. N/A).

In spring, hairy vetch continues to add N through its “seed set” stage after blooming. Biomass and N increase until maturity, giving either greater benefit or a dilemma, depending on your ability to deal with vines that become more sprawling and matted as they mature.

Mulch-retaining options include strip-tilling or strip chemical desiccation (leaving vetch untreated between the strips), mechanical killing (rotary mowing, flailing, cutting, sub-soil shearing with an undercutter, or chopping/flattening with a roller/crimper) or broadcast herbicide application.

No-till corn into killed vetch. The best time for no-till corn planting into hairy vetch varies with local rainfall patterns, soil type, desired N contribution, season length and vetch maturity.

In **southern Illinois**, hairy vetch no-tilled into fescue provided 40 to 180 lb. N/A per year over 15 years for one researcher/farmer. He used herbicide to kill the vetch about two weeks before the area’s traditional mid-May corn planting date. The 14-day interval was critical to rid the field of prairie voles, present due to the field’s thick fescue thatch.

He kills the vetch when it is in its pre-bloom or bloom stage, nearing its peak N-accumulation capacity. Further delay would risk loss of soil moisture in the dry period customary there in early June. When the no-tilled vetch was left to grow one season until seed set, it produced 6 tons of dry matter and contributed a potentially polluting 385 lb. N/A (417). This high dose of N must be managed carefully during the next year to prevent leaching or surface runoff of nitrates.

A series of trials in **Maryland** showed a different mix of conditions. Corn planting in late-April is common there, but early killing of vetch to plant corn then had the surprising effect of *decreasing* soil moisture and corn yield, as well as predictably lowering N contribution. The earlier-planted corn had less moisture-conserving residue. Late April or early May kill dates, with corn no-tilled 10 days later, consistently resulted in higher corn yields than earlier kill dates (82, 83, 84, 85). With hairy vetch and a vetch/rye mixture, summer soil water conservation by the cover crop residue had a greater impact than spring moisture depletion by the growing cover crop in determining corn yield (84, 85).

Results in the other trials, which also included a pure rye cover, demonstrated the management flexibility of a legume/grain mix. Early killed rye protects the soil as it conserves water and N, while vetch killed late can meet a large part of the N requirement for corn. The vetch/rye mixture can conserve N and soil moisture while fixing N for the subsequent crop. The vetch and vetch/rye mixture accumulated N at 130 to 180 lb./A. The mixture contained as much N or more than vetch alone (85, 86).

In an **Ohio** trial, corn no-tilled into hairy vetch at mid-bloom in May received better early season weed control from vetch mulch than corn seeded into vetch killed earlier. The late planting date decreased yield, however (189), requiring calculation to determine if lower costs for tillage, weed control, and N outweigh the yield loss.

Once vetch reaches about 50% bloom, it is easily killed by any mechanical treatment. To mow-kill for mulch, rye grown with hairy vetch improves cutting by holding the vetch off the ground to allow more complete severing of stems from roots. Rye also increases the density of residue covering the vetch stubble to prevent regrowth.

Much quicker and more energy-efficient than mowing is use of a modified Buffalo rolling stalk chopper, an implement designed to shatter standing corn stubble. The chopper’s rolling blades break over, crimp and cut crop stems at ground level, and handle thick residue of hairy vetch at 8 to 10 mph (169).

Cover Crop Roller Design Holds Promise For No-Tillers

However, timing of control and planting in a single pass could limit adoption; hope lies in breeding cover crops that flower in time for traditional planting window.

THE POSSIBILITY of using rollers to reduce herbicide use isn't new, but advances are being made to improve the machines in ways that could make them practical for controlling no-till cover crops.

Cover crop rolling is gaining visibility and credibility in tests by eight university/farmer research teams across the country. The test rollers were designed and contributed by The Rodale Institute (TRI), a Pennsylvania-based organization focused on organic agricultural research and education. The control achieved with the roller is comparable to a roller combined with a glyphosate application, according to TRI.

The Rodale crop rollers were delivered to state and federal cooperative research teams in Virginia, Michigan, Mississippi, North Dakota, Pennsylvania, Georgia, California and Iowa in Spring, 2005. Funding for the program comes from grants and contributions from the Natural Resources Conservation Service and private donors. I&J Manufacturing in Gap, Pa., fabricated the models distributed to the research teams.

"The requirement is that each research leader partners with a farmer cooperator to adapt the rollers to local conditions and cover cropping systems," explains Jeff Moyer, TRI's farm manager. "Our goal is to gain more knowledge about the soil building and weed management effects of cover crops while reducing the need for herbicides," he says.

Farmer Built. Moyer designed and built the first front-mounted TRI roller prototype in 2002 in conjunction with Pennsylvania farmer John Brubaker, whose land abuts the TRI property. The original 10-foot, 6-inch roller width is equal to 4 rows on 30-inch spacing,

with a 3-inch overlap on each end. The original design has already been modified to include a 15-foot, 6-inch model suitable for use with a 6-row planter on 30-inch rows. It can be adapted to fit a 4-row planter on 38-inch rows, and a 5-foot version for 2-row vegetable planters.

"We realize that 6-row equipment is small by today's standards, and work is under way on a system that mounts one section of the roller in front of the tractor with the remainder mounted on the planter ahead of the row units. This design will allow as wide a roller system as a farmer needs," Moyer says.

Chevron Pattern. The chevron pattern on the face of the roller came about after the designers realized that mounting the roller blades in a straight line would cause excessive bouncing, while just curving the blades in a screw pattern would act like an auger and create a pulling effect. "If you were driving up a hill that might be fine, but we don't need help pulling our tractors down the steep slopes we farm. The chevron pattern neutralizes any forces that might pull the tractor in either direction," Moyer explains. It overcomes both the bounce of straight-line blades and the auguring effect of corkscrew blades.

"In addition, with the twisted blade design, only a very small portion of the blade touches the ground at any one time as it turns, so the full pressure of the roller is applied 1 inch at a time. This roller design works better than anything we've ever used," he adds.

Prior to settling on the TRI prototype, Moyer and Brubaker studied stalk choppers with nine rolling drums arranged in two parallel rows. This design required 18 bearings and provided lots of places for green plant material to bunch

up. The TRI ground-driven roller has a single cylinder and two offset bearings inset 3 inches on either side and fronted with a shield. The blades are welded onto the 16-inch-diameter drum, but replacement blades can be purchased from the manufacturer and bolted on as needed. The 10-foot, 6-inch roller weighs 1,200 pounds empty and 2,000 pounds if filled with water.

Front Mount Benefits. The biggest advantage of the front-mounted roller is that the operator can roll the cover crop and no-till the cash crop in a single field pass, Moyer explains. In TRI trials, simultaneous rolling and no-till planting eliminated seven of the eight field passes usually necessary with conventional organic corn production, including plowing, discing, packing, planting, two rotary hoe passes and two cultivations.

Rolling the field and no-tilling in one pass also eliminates the problem of creating a thick green cover crop mat that makes it difficult to see a row marker line on a second pass for planting.

Also, planting in a second pass in the opposite direction from which the cover crop was rolled makes getting uniform seeding depth and spacing more difficult because the planter tends to stand the plant material back up. “Think of it as combing the hair on your dog backwards,” Moyer says.

“Another disadvantage of rear-mounted machines like stalk choppers is that the tractor tire is the first thing touching the cover crop. If the soil is even a little spongy, the cover crop will be pushed into the tire tracks and because the roller is running flat, it can’t crimp the depressed plant material. A week later the plants missed by the roller will be back up and growing again.”

Crop Versatility. The TRI roller concept has been tested in a wide range of winter annual cover crops, including cereal rye, hairy

vetch, wheat, triticale, oats, buckwheat, clover, winter peas and other species. Timing is the key to success, Moyer emphasizes, and a lot of farmers don’t have the patience to make it work right.

“The bottom line is that winter annuals want to die anyway, but if you time it wrong, they’re hard to kill,” he says. “If you try to roll a winter annual before it has flowered—before it has physiologically reproduced—the plant will try to stand up again and complete the job of reproduction, the most important stage of its life cycle. But, if you roll it after it has flowered, it will dry up and die.”

At least a 50 percent, and preferably a 75 to 100 percent bloom, is recommended before rolling. Moyer hopes to see plant breeders recognize the need to develop cover crop varieties with blooming characteristics that coincide with preferred crop planting windows.

“We really like to use hairy vetch on our farm, for example, because it’s a great source of nitrogen and is a very suitable crop to plant corn into. The roller crimps the stem of the hairy vetch every 7 inches, closing the plant’s vascular system and ensuring its demise.

“The problem is we would like it to flower a couple weeks earlier to fit our growing season. It’s hard for farmers to understand when it’s planting time and we’re telling them to wait a couple more weeks for their cover crop to flower,” he says.

“We need to identify the characteristics we want in cover crops and encourage plant breeders to focus on some of those. It should be a relatively easy task to get an annual crop to mature a couple weeks earlier, compared to some of the breakthrough plant breeding we’ve seen recently,” Moyer says.

continued on page 148

For More Information. Updates on roller research, more farmer stories and plans for the TRI no-till cover crop roller can be accessed at www.newfarm.org/depts/notill. To ask questions of The Rodale Institute, e-mail to info@rodaleinst.org.

See also “Where can I find information about the mechanical roller-crimper used in no-till production?” <http://attra.ncat.org/calendar/question.php/2006/05/08/p2221>.

To contact the manufacturer of commercially available cover crop rollers, visit www.croproller.com.

Editor’s Note: PURPLE BOUNTY, a new, earlier variety of hairy vetch, was released in 2006 by the USDA-Agricultural Research Service, Beltsville, MD in collaboration with the Rodale Institute, Pennsylvania State University and Cornell University.

—Ron Ross. Adapted with permission from www.no-tillfarmer.com

No-till vegetable transplanting. Vetch that is suppressed or killed without disturbing the soil maintains moisture well for transplanted vegetables. No-till innovator Steve Groff of Lancaster County, Pa., uses the rolling stalk chopper to create a killed organic mulch. His favorite mix is 25

**Winter hardy
through the
warmer parts of
Zone 4, few
legumes can rival
hairy vetch’s N
contributions.**

lb. hairy vetch, 30 lb. rye and 10 lb. crimson clover/A.

No-till, delayed kill. Farmers and researchers are increasingly using a roller/crimper to kill hairy vetch and other cover crops (11). Jeff Moyer and others at the Rodale Institute in Kutztown, Pa., roll hairy vetch and other cover crops in late May or

early June (at about 50% flower). The modified roller is front-mounted, and corn is no-tilled on the same pass (303). See *Cover Crop Roller Design Holds Promise For No-Tillers*, p. 146.

Also useful in killing hairy vetch on raised beds for vegetables and cotton is the improved prototype of an undercutter that leaves severed residue virtually undisturbed on the surface (96). The undercutter tool includes a flat roller attachment, which, by itself, usually provides only partial suppression unless used after flowering.

Herbicides will kill vetch in three to 30 days, depending on the material used, rate, growth stage and weather conditions.

Vetch incorporation. As a rule, to gauge the optimum hairy vetch kill date, credit vetch with adding two to three pounds of N per acre per sunny day after full spring growth begins. Usually, N contribution will be maximized by early bloom (10-25 percent) stage.

Cutting hairy vetch close to the ground at full bloom stage usually will kill it. However, waiting this long means it will have maximum top growth, and the tangled mass of mature vetch can overwhelm many smaller mowers or disks. Flail mowing before tillage helps, but that is a time and horsepower intensive process. Sickle-bar mowers should only be used when the vetch is well supported by a cereal companion crop and the material is dry (422).

Management Cautions

About 10 to 20 percent of vetch seed is “hard” seed that lays ungerminated in the soil for one or more seasons. This can cause a weed problem, especially in winter grains. In wheat, a variety of herbicides are available, depending on crop growth stage. After a corn crop that can utilize the vetch-produced N, you could establish a hay or pasture crop for several years.

Don’t plant hairy vetch with a winter grain if you want to harvest grain for feed or sale.

Production is difficult because vetch vines will pull down all but the strongest stalks. Grain contamination also is likely if the vetch goes to seed before grain harvest. Vetch seed is about the same size as wheat and barley kernels, making it hard and expensive to separate during seed cleaning (361). Grain price can be markedly reduced by only a few vetch seeds per bushel.

A severe freeze with temperatures less than 5° F may kill hairy vetch if there is no snow cover, reducing or eliminating the stand and most of its N value. If winterkill is possible in your area, planting vetch with a hardy grain such as rye ensures spring soil protection.

Pest Management

In legume comparison trials, hairy vetch usually hosts numerous small insects and soil organisms (206). Many are beneficial to crop production, (see below) but others are pests. Soybean cyst nematode (*Heterodera glycines*) and root-knot nematode (*Meloidogyne* spp.) sometimes increase under hairy vetch. If you suspect that a field has nematodes, carefully sample the soil after hairy vetch. If the pests reach an economic threshold, plant nematode-resistant crops and consider using another cover crop.

Other pests include cutworms (361) and southern corn rootworm (67), which can be problems in no-till corn, tarnished plant bug, noted in coastal Massachusetts (56), which readily disperses to other crops, and two-spotted spider mites in Oregon pear orchards (142). Leaving unmowed remnant strips can lessen movement of disruptive pests while still allowing you to kill most of the cover crop (56).

Prominent among beneficial predators associated with hairy vetch are lady beetles, seven-spotted ladybeetles (56) and bigeyed bugs (*Geocoris* spp.). Vetch harbors pea aphids (*Acyrtosiphon pisum*) and blue alfalfa aphids (*Acyrtosiphon kondoi*) that do not attack pecans but provide a food source for aphid-eating insects that can disperse into pecans (58). Similarly, hairy vetch blossoms harbor flower thrips (*Frankliniella* spp.), which in turn attract important thrip predators such as insidious flower bugs (*Orius insidiosus*)

and minute pirate bugs (*Orius tristicolor*).

Two insects may reduce hairy vetch seed yield in heavy infestations: the vetch weevil or vetch bruchid. Rotate crops to alleviate buildup of these pests (361).

CROP SYSTEMS

In no-till systems, killed hairy vetch creates a short-term but effective spring/summer mulch, especially for transplants. The mulch retains moisture, allowing plants to use mineralized nutrients better than unmulched fields. The management challenge is that the mulch also lowers soil temperature, which may delay early season growth (361). One option is to capitalize on high quality, low-cost tomatoes that capture the late-season market premiums. See *Vetch Beats Plastic* (p. 150).

How you kill hairy vetch influences its ability to suppress weeds. Durability and effectiveness as a light-blocking mulch are greatest where the stalks are left whole. Hairy vetch severed at the roots or sickle-bar mowed lasts longer and blocks more light than flailed vetch, preventing more weed seeds from germinating (96, 411).

Southern farmers can use an overwintering hairy vetch crop in continuous no-till cotton. Vetch mixed with rye has provided similar or even increased yields compared with systems that include conventional tillage, winter fallow weed cover and up to 60 pounds of N fertilizer per acre. Typically, the cover crops are no-till drilled after shredding cotton stalks in late October. Covers are spray killed in mid-April ahead of cotton planting in May. With the relatively late fall planting, hairy vetch delivers only part

Mix hairy vetch with cereal grains to reduce the risk of N leaching.

Note: An unmowed rye/hairy vetch mix sustained a population of aphid-eating predators that was six times that of the unmowed volunteer weeds and 87 times that of mown grass and weeds (57).

Vetch Beats Plastic

BELTSVILLE, Md.—Killed cover crop mulches can deliver multiple benefits for no-till vegetable crops (1, 2, 3, 4). The system can provide its own N, quell erosion and leaching, and displace herbicides. It's also more profitable than conventional commercial production using black plastic mulch. A budget analysis showed it also should be the first choice of "risk averse" farmers, who prefer certain although more modest profit over higher average profit that is less certain (224).

The key to the economic certainty of a successful hairy vetch planting is its low cost compared with the black plastic purchase, installation and removal.

From refining his own research and on-farm tests in the mid-Atlantic region for several years, Aref Abdul-Baki, formerly of the USDA's Beltsville (Md.) Agricultural Research Center, outlines his approach:

- Prepare beds—just as you would for planting tomatoes—at your prime time to seed hairy vetch.
- Drill hairy vetch at 40 lb./A, and expect about 4 inches of top growth before dormancy, which stretches from mid-December to mid-March in Maryland.
- After two months' spring growth, flail mow or use other mechanical means to suppress the hairy vetch. Be ready to remove or use herbicides to clean up trouble spots where hairy vetch regrows or weeds appear.

- Transplant seedlings using a minimum tillage planter able to cut through the mulch and firm soil around the plants.

The hairy vetch mulch suppresses early season weeds. It improves tomato health by preventing soil splashing onto the plants, and keeps tomatoes from soil contact, improving quality. Hairy vetch-mulched plants may need more water. Their growth is more vigorous and may yield up to 20 percent more than those on plastic. Completing harvest by mid-September allows the field to be immediately reseeded to hairy vetch. Waiting for vetch to bloom in spring before killing it and the tight fall turnaround may make this system less useful in areas with a shorter growing season than this Zone 7, mid-Atlantic site.

Abdul-Baki rotates season-long cash crops of tomatoes, peppers and cantaloupe through the same plot between fall hairy vetch seedings. He shallow plows the third year after cantaloupe harvest and seeds hairy vetch for flat-field crops of sweet corn or snap beans the following summer.

He suggests seeding rye (40 lb./A) with the vetch for greater biomass and longer-lasting mulch. Adding 10-12 lb./A of crimson clover will aid in weed suppression and N value. Rolling the covers before planting provides longer-lasting residue than does mowing them. Some weeds, particularly perennial or winter annual weeds, can still escape this mixture, and may require additional management (4).

of its potential N in this system. It adds cost, but supplies erosion control and long-term soil improvement (35).

Cotton yields following incorporated hairy vetch were perennial winners for 35 years at a northwestern Louisiana USDA site. Soil organic matter improvement and erosion control were additional benefits (276).

Other Options

Spring sowing is possible, but less desirable than fall establishment because it yields significantly less biomass than overwintering stands. Hot weather causes plants to languish.

Hairy vetch makes only fair grazing—livestock do not relish it.

Harvesting seed. Plant hairy vetch with grains if you intend to harvest the vetch for seed. Use a moderate seeding rate of 10-20 lb./A to keep the stand from getting too rank. Vetch seed pods will grow above the twining vetch vines and use the grain as a trellis, allowing you to run the cutter bar higher to reduce plugging of the combine. Direct combine at mid-bloom to minimize shattering, or swath up to a week later. Seed is viable for at least five years if properly stored (361).

If you want to save dollars by growing your own seed, be aware that the mature pods shatter easily, increasing the risk of volunteer weeds. To keep vetch with its nurse crop, harvest vetch with a winter cereal and keep seed co-mingled for planting. Check the mix carefully for weed seeds.

COMPARATIVE NOTES

Hairy vetch is better adapted to sandy soils than crimson clover (344), but is less heat-tolerant than LANA woollypod vetch. See *Woollypod Vetch* (p. 185).

Cultivars. MADISON—developed in Nebraska—tolerates cold better than other varieties. Hairy vetches produced in Oregon and California tend to be heat tolerant. This has resulted in two apparent types, both usually sold as “common” or “variety not stated” (VNS). One has noticeably hairy, bluish-green foliage with bluish flowers and is more cold-tolerant. The other type has smoother, deep-green foliage and pink to violet flowers.

A closely related species—LANA woollypod vetch (*Vicia dasycarpa*)—was developed in Oregon and is less cold tolerant than *Vicia villosa*. Trials in southeastern Pennsylvania with many accessions of hairy vetch showed big flower vetch (*Vicia grandiflora*, cv WOODFORD) was the only vetch species hardier than hairy vetch. EARLY COVER hairy vetch is about 10 days earlier than regular common seed. PURPLE BOUNTY, released in 2006, is a few days earlier and provides more biomass and better ground cover than EARLY COVER.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

RED CLOVER

Trifolium pratense

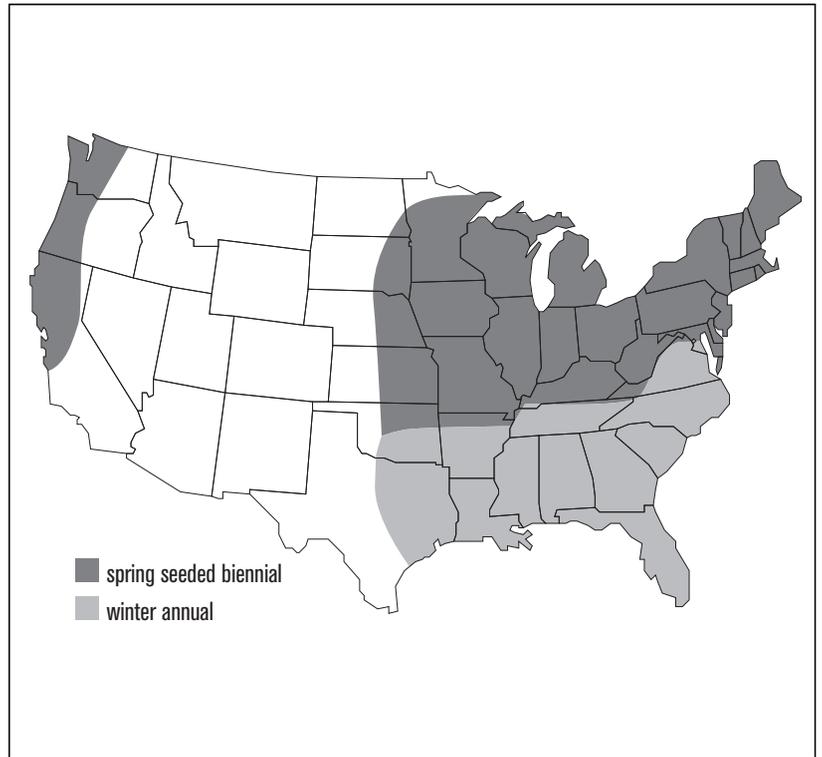
Also called: medium red clover (multi-cut, early blooming, June clover); mammoth clover (singlecut, late blooming, Michigan red)

Type: short-lived perennial, biennial or winter annual legume

Roles: N source, soil builder, weed suppressor, insectary crop, forage

Mix with: small grains, sweetclover, corn, soybeans, vegetables, grass forages

See charts, p. 66 to 72, for rankings and management summary.



Red clover is a dependable, low-cost, readily available workhorse that is winter hardy in much of the U.S. (Hardiness Zone 4 and warmer). Easily overseeded or frostseeded into standing crops, it creates loamy topsoil, adds a moderate amount of N, helps to suppress weeds and breaks up heavy soil. Its most common uses include forage, grazing, seed harvest, plowdown N and, in warmer areas, hay. It's a great legume to frostseed or interseed with small grains where you can harvest grain as well as provide weed suppression and manage N.

BENEFITS

Crop fertility. As a cover crop, red clover is used primarily as a legume green manure killed ahead of corn or vegetable crops planted in early summer. Full-season, over-wintered red clover can produce 2 to 4 T dry matter/A and fix 70 to 150 lb. N/A. In Ohio, over-wintered mammoth and medium red clover contained about 75 lb. N/A by May 15, increasing to 130 lb. N by June 22 (366).

Two years of testing in Wisconsin showed that conventionally planted corn following red clover

yielded the same as corn supplied with 160 lb. N/A, with less risk of post-harvest N leaching. Corn and the soil testing showed that 50 percent of the cover crop N was released in the first month after incorporation, corresponding well with corn's fertility demand. Post-harvest soil N levels in the clover plots were the same or less than the fertilized plots, and about the same as unfertilized plots (401).

Widely adapted. While many other legumes can grow quicker, produce more biomass and fix more nitrogen, few are adapted to as many soil types and temperate climatic niches as red clover. As a rule, red clover grows well wherever corn

Red clover can yield 2 to 3 tons of dry matter and 70 to 150 lb. N/A

grows well. It does best in cool conditions. In southern Canada and the northern U.S., and in the higher elevations of the Southeast and West, red clover grows as a biennial or short-lived perennial. At lower elevations in the Southeast, it grows as a winter annual, and at lower elevations in the West and Canada, it grows under irrigation as a biennial (120). It grows in any loam or clay soil, responding best to well-drained, fertile soils, but also tolerates less well-drained conditions.

Many economic uses. Red clover has been a popular, multi-use crop since European immigrant farmers brought it to North America in the 1500s. It remains an important crop thanks to its greater adaptability, lower seeding cost and easier establishment than alfalfa. It can produce up to 8,000 lb. biomass/A.

A red clover/small grain mix has been a traditional pairing that continues to be profitable. A rotation of corn and oats companion-seeded with red clover proved as profitable as continuous corn receiving 160 lb. N/A in a four-year Wisconsin study (400). For more information, see the Wisconsin Integrated Cropping Systems Trial (449) and the final report of this project, partially funded by SARE (328).

Red clover was the most profitable of five legumes under both seeding methods in the trial—sequentially planted after oats harvest or companion planted with oats in early spring. The companion seedings yielded nearly twice as much estimated fertilizer replacement value as the sequential seedings. The work showed that red clover holds great potential to reduce fertilizer N use for corn grown in rotation (401).

In Michigan, red clover frost-seeded into winter wheat suppressed common ragweed growth through wheat harvest and into the summer. The red clover did not provide complete ragweed control, but there was no adverse effect on wheat yield (297).

Red clover sown as a companion with spring oats outperformed the other legumes, which suffered from insect damage, mechanical damage during oat harvest and slow subsequent regrowth. The short season proved inadequate for sequentially seeded legumes with the exception of hairy vetch, which was nearly as profitable as the red clover (400).

The role of red clover's N contribution in the rotation grew more significant as N prices increased in the late 1990s (and 2007!), even though clover seed price also increased from the original 1989 calculations (398).

Soil conditioner. Red clover is an excellent soil conditioner, with an extensive root system that permeates the topsoil. Its taproot may penetrate several feet.

Attracts beneficial insects. Red clover earned a co-starring role with LOUISIANA S-1 white clover in pecan orchard recommendations from Oklahoma State University. Red clover attracts more beneficials than white clover, which features higher N fixation and greater flood tolerance than red clover (261).

Two Types

Two distinct types of red clover have evolved from the same species. Be sure you plant a multi-cut cultivar if you plan to make more than one green manure cutting, or to maintain the stand to prepare for a late-summer vegetable planting.

Medium red clover. Medium red (some call it multi-cut) grows back quickly, and can be cut once late in the seeding year and twice the following year. For optimum N benefit and flexible cropping options from the planting (allowing it to overwinter as a soil-protecting mulch), you can use it for hay, grazing or seed throughout the second season. Seed may be up to 25 percent more expensive than single-cut. See Chart 3B: *Planting* (p. 70).

Mammoth red clover produces significant biomass and as much N as medium red in a single first cutting, but does not produce as much total biomass and N as medium red's multiple cuttings over time. Use this "single-cut" red clover where a field will be all-clover just during the seeding year. Slow-growing mammoth doesn't bloom the establishment year and regrows quite slowly after cutting, but can provide good biomass by the end of even one growing season.

A single cutting of mammoth will give slightly more biomass—at a slightly lower cost—than a single cutting of medium red. Where multiple cuttings or groundcover are needed in the second season, medium red clover's higher seed cost is easily justified (197).

Some types of mammoth do better overseeded into wheat than into oats. ALTASWEDE (Canadian) mammoth is not as shade tolerant as MICHIGAN mammoth, but works well when seeded with oats. MICHIGAN mammoth shows the best vigor when frostseeded into wheat, but is not as productive as medium red (229).

MANAGEMENT

Establishment & Fieldwork

In spring in cool climates, red clover germinates in about seven days—quicker than many legumes—but seedlings develop slowly, similar to winter annual legumes. Traditionally it is drilled at 10 to 12 lb./A with spring-sown grains, using auxiliary or "grass seed" drill boxes. Wisconsin researchers who have worked for several years to optimize returns from red clover/oats interseedings say planting oats at 3 to 4 bu./A gives good stands of clover without sacrificing grain yield (398).

Red clover's tolerance of shade and its ability to germinate down to 41° F give it a remarkable range of establishment niches.

It can be **overseeded** at 10 to 12 lb./A into:

- **Dormant winter grains** before ground thaws. This "frostseeding" method relies on movement of the freeze-thaw cycle to work seed into sufficient seed-soil contact for germination. If the soil is level and firm, you can broadcast seed over snow cover on level terrain. You can seed the clover with urea if fertilizer application is uniform (229). Use just enough N fertilizer to support proven small-grain yields, because excess N application will hinder clover establishment. To reduce small grain competition with clover in early spring, graze or clip the small grain in early spring just before the stems begin to grow (120). Hoof impact from grazing also helps ensure seed-to-soil contact.

- **Summer annuals** such as oats, barley, spelt or spring wheat before grain emergence.

- **Corn at layby.** Wait until corn is 10 to 12 inches tall, and at least 6 weeks (check labels!) after application of pre-emergent herbicides such as atrazine. Clover sown earlier in favorable cooler conditions with more light may compete too much for water. Later, the clover will grow more slowly and not add substantial biomass until after corn harvest lets light enter (197). Dairy producers often broadcast red clover after corn silage harvest.

- **After wheat harvest.** Red clover logged a fertilizer replacement value of 36 lb. N/A in a two-year Michigan trial that used N isotopes to track nitrogen fixation. Red clover and three other legumes were no-till drilled into wheat stubble in August, then chemically killed by mid-May just ahead of no-till corn. Clover even in this short niche shows good potential to suppress weeds and reduce N fertilizer application (140).

- **Soybeans at leaf-yellowing.** Sowing the clover seed with annual or perennial ryegrass as a nurse crop keeps the soil from drying out until the clover becomes established (197).

Whenever possible, lightly incorporate clover seed with a harrow. Wait at least six weeks (check labels!) to establish a red clover stand in soil treated with pre-emergent herbicides such as atrazine.

Marianne Sarrantonio



RED CLOVER (*Trifolium pratense*)

Killing

For peak N contribution, kill red clover at about mid-bloom in spring of its second season. If you can't wait that long, kill it earlier to plant field corn or early vegetables. If you want to harvest the first cutting for hay, compost or mulch, kill the regrowth in late summer as green manure for fall vegetables (197). If avoiding escapes or clover regrowth is most important, terminate as soon as soil conditions allow.

Actively growing red clover can be difficult to kill mechanically, but light fall chisel plowing followed by a second such treatment has worked well in sandy loam Michigan soils.

To kill clover mechanically in spring, you can till, chop or mow it any time after blooming starts. You can also shallow plow, or use a moldboard plow. Chop (using a rolling stalk chopper), flail or sicklebar mow about seven to 10 days ahead of no-till planting, or use herbicides. Roundup Ready® soybeans can be drilled into living red clover and sprayed later.

A summer mowing can make it easier to kill red clover with herbicides in fall. Michigan recommendations call for mowing (from mid-August in northern Michigan to early September in southern Michigan), then allowing regrowth for four weeks before spraying. The daytime high air tem-

perature should be above 60° F (so that the plants are actively growing). When soil temperature drops below 50° F, biological decomposition slows to the point that mineralization of N from the clover roots and top-growth nearly stops (229).

Field Evaluation

In Michigan, about half of the total N fixed by a legume will mineralize during the following growing season and be available to that season's crop (229). However, Wisconsin research shows release may be faster. There, red clover and hairy vetch released 70 to 75 percent of their N in the first season (401).

Rotations

Rotation niches for red clover are usually between two non-leguminous crops. Spring seeding with oats or frostseeding into wheat or barley are common options (34). The intersowing allows economic use of the land while the clover is developing. This grain/red clover combination often follows corn, but also can follow rice, sugar beets, tobacco or potatoes in two-year rotations. For three-year rotations including two full years of red clover, the clover can be incorporated or surface-applied (clipped and left on the field) for green manure, cut for mulch or harvested for hay (120).

Red clover in a corn>soybean>wheat/red clover rotation in a reduced-input system outperformed continuous corn in a four-year Wisconsin study. The legume cover crop system used no commercial fertilizer, no insecticides and herbicides on only two occasions—once to spot spray Canada thistles and once as a rescue treatment for soybeans. Rotary hoeing and cultivating provided weed control.

Gross margins were \$169 for the corn>soybeans>wheat/red clover and \$126 for continuous corn using standard agricultural fertilizers, insecticides and herbicides. Top profit in the study went to a corn>soybean rotation with a gross margin of \$186, using standard inputs (272, 398, 167).

Ohio farmer Rich Bennett frostseeds redclover (10-12 lb./A) into wheat in February. He gets a decent stand of clover that keeps weeds down in summer after wheat harvest. The clover overwin-

ters and continues to grow in spring. He waits as long as possible, and then kills the clover with a disc and roll (two passes) in late April and plants corn. He doesn't add any fertilizer N and the corn averages 165 bu/A on his Ottokee fine sandy soil.

If summer annual grasses are a problem, red clover is not your best option because it allows the grasses to set seed, even under a mowing regime.

Pest Management

If poor establishment or winterkill leads to weed growth that can't be suppressed with clipping or grazing, evaluate whether the anticipated cover crop benefits warrant weed control. Take care to completely kill the cover crop when planting dry beans or soybeans after clover. Unless you are using herbicide-tolerant crops, you have limited herbicide options to control clover escapes that survive in the bean crop (229).

Root rots and foliar diseases typically kill common medium red clover in its second year, making it function more like a biennial than a perennial. Disease-resistant cultivars that persist three to four years cost 20 to 40 cents more per pound and are unnecessary for most green manure applications. When fertilizer N cost is high, however, remember that second-year production for some improved varieties is up to 50 percent greater than for common varieties.

Bud blight can be transmitted to soybeans by volunteer clover plants.

Other Management Options

Mow or allow grazing of red clover four to six weeks before frost in its establishment year to prepare it for overwintering. Remove clippings for green manure or forage to prevent plant disease. Red clover reaches its prime feeding value at five to 15 days after first bloom.

Under ideal conditions, medium red clover can be cut four times, mammoth only once. Maximum cutting of medium one year will come at the expense of second-year yield and stand longevity. Red clover and red clover/grass mixtures make good silage if wilted slightly before ensiling or if other preservative techniques are used (120).

If an emergency forage cut is needed, harvest red clover in early summer, then broadcast and lightly incorporate millet seed with a tine harrow or disk. Millet is a heat-loving grass used as a cover and forage in warm-soil areas of Zone 6 and warmer.

Few legumes are as widely adapted as red clover, which can be used as green manure, forage or seed crop.

COMPARATIVE NOTES

Medium red clover has similar upper-limit pH tolerance as other clovers at about 7.2. It is generally listed as tolerating a minimum pH of 6.0—not quite as low as mammoth, white or alsike (*Trifolium hybridum*) clovers at 5.5—but it is said to do well in Florida at the lower pH. Red clover and sweetclover both perform best on well-drained soils, but will tolerate poorly drained soils. Alsike thrives in wet soils.

Red clover has less tendency to leach phosphorus (P) in fall than some non-legume covers. It released only one-third to one-fifth the P of annual ryegrass and oilseed radish, which is a winter-annual brassica cover crop that scavenges large amounts of N. Figuring the radish release rates—even balanced somewhat by the erosion suppression of the covers—researchers determined that P runoff potential from a quick-leaching cover crop can be as great as for unincorporated manure (274).

For *early* fall plowdown, alsike clover may be a cheaper N source than mammoth, assuming similar N yields.

Red clover and alfalfa showed multi-year benefits to succeeding corn crops, justifying a credit of 90 lb. N/A the first year for red clover (197) and 50 lb. N/A the second year. The third legume in the trial, birdsfoot trefoil (*Lotus corniculatus*), was the only one of the three that had enough third-year N contribution to warrant a credit of 25 lb. N/A (148).

Clark, Andy (ed.). 2007. *Managing Cover Crops Profitably*, 3rd ed. Sustainable Agriculture Network, Beltsville, MD.

Cultivars. KENLAND, KENSTAR, ARLINGTON, and MARATHON are improved varieties of medium red clover with specific resistance to anthracnose and mosaic virus strains. They can persist three or even four years with ideal winter snow cover

(90). CHEROKEE has performed well in Iowa (384), is suited to the Coastal Plain and lower South, and has superior resistance to rootknot nematode.

Seed sources. See *Seed Suppliers* (p. 195). ❄️

WHITE CLOVER

Trifolium repens

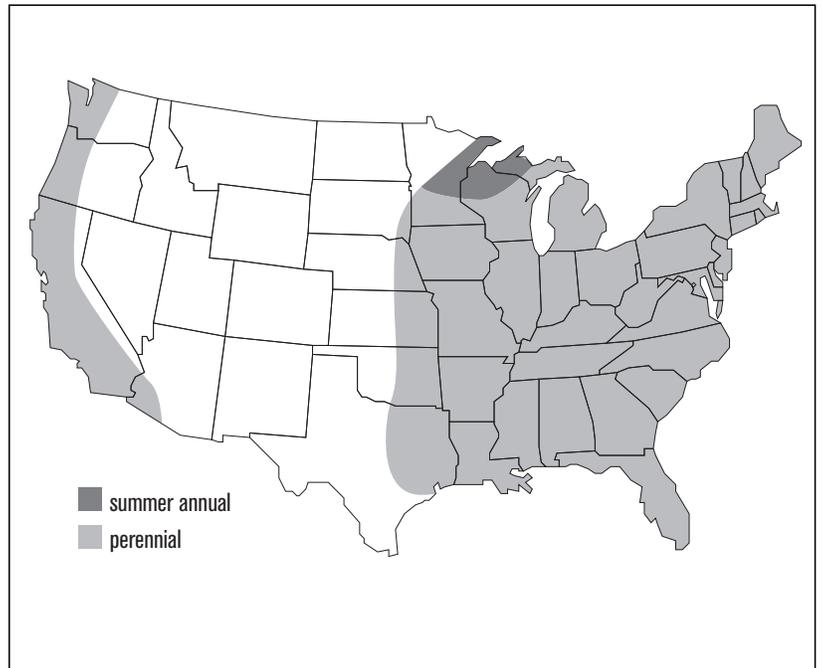
Also called: Dutch White, New Zealand White, Ladino

Type: long-lived perennial or winter annual legume

Roles: living mulch, erosion protection, green manure, beneficial insect attraction

Mix with: annual ryegrass, red clover, hard fescue or red fescue

See charts, pp. 66 to 72, for ranking and management summary.



White clovers are a top choice for “living mulch” systems planted between rows of irrigated vegetables, fruit bushes or trees. They are persistent, widely adapted perennial nitrogen producers with tough stems and a dense shallow root mass that protects soil from erosion and suppresses weeds. Depending on the type, plants grow just 6 to 12 inches tall, but thrive when mowed or grazed. Once established, they stand up well to heavy field traffic and thrive under cool, moist conditions and shade.

Three types: Cultivars of white clover are grouped into three types by size. The lowest growing type (Wild White) best survives heavy traffic and grazing. Intermediate sizes (Dutch White, New Zealand White and Louisiana S-1) flower earlier and more profusely than the larger types, are more heat-tolerant and include most of the economically important varieties. The large (Ladino) types produce the most N per acre of any white types, and are valued for forage quality, especially on poorly drained soil. They are generally less durable, but may be two to four times taller than intermediate types.

Intermediate types of white clover include many cultivated varieties, most originally bred for forage.

The best of 36 varieties tested in north-central Mississippi for cover crop use were ARAN, GRASSLAND KOPU and KITAOOHA. These ranked high for all traits tested, including plant vigor, leaf area, dry matter yield, number of seed-heads, lateness of flowering and upright stems to prevent soil contact. Ranking high were ANGEL GALLARDO, CALIFORNIA LADINO and widely used LOUISIANA S-1 (392).

White clover performs best when it has plenty of lime, potash, calcium and phosphorus, but it tolerates poor conditions better than most clovers. Its perennial nature depends on new plants continually being formed by its creeping stolons and, if it reaches maturity, by reseeding.

White clover is raised as a winter annual in the South, where drought and diseases weaken stands. It exhibits its perennial abilities north through Hardiness Zone 4. The short and intermediate types are low biomass producers, while the large ladino types popular with graziers can produce as much biomass as any clover species.

BENEFITS

Fixes N. A healthy stand of white clover can produce 80 to 130 lb. N/A when killed the year after establishment. In established stands, it also may

Tough, low-growing and shade tolerant, this perennial is often used as a living mulch in vegetable systems.

release. The low C:N ratio of stems and leaves causes them to decompose rapidly to release N.

Tolerates traffic. Wherever there's intensive field traffic and adequate soil moisture, white clover makes a good soil covering that keeps alleyways green. It reduces compaction and dust while protecting wet soil against trauma from vehicle wheels. White clover converts vulnerable bare soil into biologically active soil with habitat for beneficial organisms above and below the soil surface.

Premier living mulch. Their ability to grow in shade, maintain a low profile, thrive when repeatedly mowed and withstand field traffic makes intermediate and even short-stemmed white clovers ideal candidates for living mulch systems. To be effective, the mulch crop must be managed so it doesn't compete with the cash crop for light, nutrients and moisture. White clover's persistence in the face of some herbicides and minor tillage is used to advantage in these systems (described below) for vegetables, orchards and vineyards.

Value-added forage. Grazed white clover is highly palatable and digestible with high crude protein (about 28 percent), but it poses a bloat risk in ruminants without careful grazing management practices.

Spreading soil protector. Because each white clover plant extends itself by sending out root-like stolons at ground level, the legume spreads over time to cover and protect more soil surface. Dropped leaves and clipped biomass effectively mulch stolons, encouraging new plants to take

provide some N to growing crops when it is managed as a living mulch between crop rows. Because it contains more of its total N in its roots than other legumes, partial tilling is an especially effective way to trigger N

root each season. Reseeding increases the number of new plants if you allow blossoms to mature.

Fits long, cool springs. In selecting a fall-seeded N-producer, consider white clover in areas with extended cool springs. MERIT ladino clover was the most efficient of eight major legumes evaluated in a Nebraska greenhouse for N₂ fixed per unit of water at 50° F. Ladino clover, as well as hairy vetch and fava beans (*Vicia faba*) were the only legumes to grow well at the 50° F temperature (334).

Overseeded companion crop. Whether frost-seeded in early spring into standing grain, broadcast over vegetables in late spring or into sweet corn in early summer, white clover germinates and establishes well under the primary crop. It grows slowly while shaded as it develops its root system, then grows rapidly when it receives more light.

MANAGEMENT

Establishment & Fieldwork

Widely adapted. White clover can tolerate wet soil—even short flooding—and short dry spells, and survives on medium to acid soils down to pH 5.5. It volunteers on a wider range of soils than most legumes, but grows better in clay and loam soils than on sandy soils (120). Ladino prefers sandy loam or medium loam soils.

Use higher seeding rates (5 to 9 lb./A drilled, 7 to 14 lb./A broadcast) when you overseed in adverse situations caused by drought, crop residue or vegetative competition. Drill 4 to 6 lb./A when mixing white clover with other legumes or grasses to reduce competition for light, moisture and nutrients.

Frostseeding of small-seeded clovers (such as alsike and white) should be done early in the morning when frost is still in the soil. Later in the day, when soil is slippery, stand establishment will be poor. Frostseed early enough in spring to allow for several freeze-thaw cycles.

Late-summer seeding must be early enough to give white clover time to become well established, because fall freezing and thawing can read-

ily heave the small, shallow-rooted plants. Seeding about 40 days before the first killing frost is usually enough time. Best conditions for summer establishment are humid, cool and shaded (120, 361). Legumes suffer less root damage from frost heaving when they are planted with a grass.

In warmer regions of the U.S. (Zone 8 and warmer), every seeding should be inoculated. In cooler areas, where N-fixing bacteria persist in the soil for up to three years, even volunteer wild white clover should leave enough bacteria behind to eliminate the need for inoculation (120).

Mowing no lower than 2 to 3 inches will keep white clover healthy. To safely overwinter white clover, leave 3 to 4 inches (6 to 8 inches for taller types) to prevent frost damage.

Killing

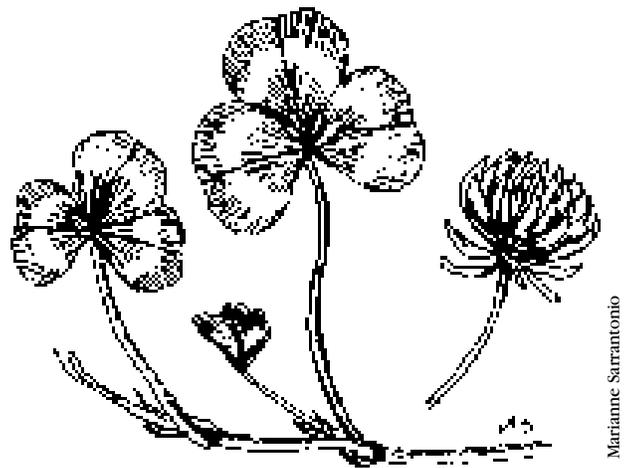
Thorough uprooting and incorporation by chisel or moldboard plowing, field cultivating, undercutting or rotary tilling, or—in spring—use of a suitable herbicide will result in good to excellent kill of white clover. Extremely close mowing and partial tillage that leaves any roots undisturbed will suppress, but not kill, white clover.

Pest Management

Prized by bees. Bees work white clover blossoms for both nectar and pollen. Select insect-management measures that minimize negative impact on bees and other pollinators. Michigan blueberry growers find that it improves pollination, as does crimson clover (see *Clovers Build Soil, Blueberry Production*, p. 182).

Insect/disease risks. White clovers are fairly tolerant of nematodes and leaf diseases, but are susceptible to root and stolon rots. Leading insect pests are the potato leafhopper (*Empoasca fabae*), meadow spittlebug (*Philaenis spumarius*), clover leaf weevil (*Hypera punctata*), alfalfa weevil (*Hypera postica*) and Lygus bug (*Lygus* spp.).

If not cut or grazed to stimulate new growth, the buildup of vegetation on aged stolons and stems creates a susceptibility to disease and insect problems. Protect against pest problems by selecting resistant cultivars, rotating crops, maintaining soil fertility and employing proper cutting schedules (361).



Marianne Sarrantonio

WHITE CLOVER (*Trifolium repens*—intermediate type)

Crop Systems

Living mulch systems. As a living mulch, white clover gives benefits above and below ground while it grows between rows of cash crops, primarily in fruits, vegetables, orchards and vineyards. Living mulch has not proved effective in agronomic crops to this point. To receive the multiple benefits, manage the covers carefully throughout early crop growth—to keep them from competing with the main crop for light, nutrients, and especially moisture—while not killing them. Several methods can do that effectively.

Hand mowing/in-row mulch. Farmer Alan Matthews finds that a self-propelled 30-inch rotary mower controls a clover mix between green pepper rows in a quarter-acre field. He uses 40-foot wide, contour strip fields and the living mulch to help prevent erosion on sloping land near Pittsburgh, Pa. In his 1996 SARE on-farm research, he logged \$500 more net profit per acre on his living mulch peppers than on his conventionally produced peppers (259).

Matthews mulches the transplants with hay, 12 inches on each side of the row. He hand-seeds the cover mix at a heavy 30 lb./A between the rows. The mix is 50 percent white Dutch clover, 30 percent berseem clover, and 20 percent HUIA white clover, which is a bit taller than the white Dutch. He mows the field in fall, then broadcasts medium red clover early the next spring to establish a hay

Clovers Build Soil, Blueberry Production

In the heart of blueberry country in the leading blueberry state in the U.S., Richard James “RJ” Rant and his mother, Judy Rant, are breaking new ground and reaping great rewards. Thanks to cover crops such as white and crimson clover taking center stage on their two family farms, the blueberry crop is thriving and the farmers are reaping significant rewards.

The Rants’ soil is also on the receiving end of the multiple benefits of white and crimson clover cover crops.

Judy and her husband, Richard Rant, planted their first bushes in the early 1980s while both were still working full time off the farm. They managed the farm until retirement without going into debt—something of an accomplishment during that period—but the operation never really took off. Still in high school when his father passed away, RJ Rant stepped into the operation during college.

Choosing farming over graduate school, RJ began a quest to improve the blueberry operation and its bottom line. His focus on soil-building and cover crops proved key to the success of their operation, now expanded

to two farms: Double-R Blueberry Farm and Wind Dancer Farms, jointly operated by RJ and his mother, Judy.

Michigan blueberry farmers have been using cover crops for many years, and top-producing Ottawa County farmers are no exception. Growing blueberry bushes on ten-foot centers, there is a lot of space between rows that farmers try to manage as economically and efficiently as possible. Seeking something that will not compete with the cash crop, most farmers choose rye or sod. Both require significant management in terms of time and labor, not to mention seed and fuel costs to plant and kill.

RJ Rant took a different tack. Their sandy loam soils were decent but not excellent, and his research led him to focus his efforts on improving the soil by reducing tillage and planting cover crops. While rye, an annual cover crop, required tillage in fall before planting and in spring to kill and incorporate, perennial white clover could be grown for two or more years without tilling. Because it is low-growing, the clover required less labor in planting and mowing.

field and replace the berseem, which is not winterhardy (259).

New Zealand white clover provided good weed control for winter squash in the wetter of two years in a New York trial. It was used in an experimental non-chemical system relying on over-the-row compost for in-row weed control. Plants were seeded into tilled strips 16 inches wide spaced 4 feet apart. Poor seed establishment and lagging clover growth in the drier year created weed problems, especially with perennial competitors. The living mulch/compost system yielded less than a conventionally tilled and fertilized control both years, due in part to delayed crop development from the in-row compost (282).

The research showed that in dry years, mowing alone won’t suppress a living mulch enough to keep it from competing for soil moisture with crops in 16-inch rows. Further, weeds can be even more competitive than the clover for water during these dry times (282).

A California study showed that frequent mowing can work with careful management. A white clover cover reduced levels of cabbage aphids in harvested broccoli heads compared with clean-cultivated broccoli. The clover-mulched plants, in strip-tilled rows 4 inches wide, had yield and size comparable to clean cultivated rows. However, only intensive irrigation and mowing prevented moisture competition. To be profitable commercially, the system would require irrigation or a less

“There are so many positive things I could say about cover crops,” Rant says. “The reason I keep using them is because they save me time and money.”

Although he started his research and planted his first Alsike clover crop on his own, RJ soon found research partners at Michigan State University. He cooperates with researcher Dale Mutch to fine-tune cover crop selection, planting methods and management options.

“I get really excited when I think about improving my soils,” Rant says. “I see my fields as one unified system, and the biology of the soil in the inter-rows is as important as the soil and fertility up and down my blueberry rows.”

Early screening of different cover crops led Rant to further test crimson clover, a winter annual cover crop that not only grows well in fall and spring, but also shows great potential to reseed itself, further reducing costs. They have also tested red clover, small white clover, mustard, rye and spring buckwheat. Rant says white clover is his favorite because it is low growing and out-competes weeds.

Soil-building remains a primary objective of Rants cover crop program. Compacted soils are a problem for blueberries, which prefer loose, friable soil. To build better soil structure, Rant is working with MSU’s Mutch to improve soil organic matter with cover crop mulches and manures.

Mutch and Rant are studying crimson clover reseeding, another cost-saving measure, comparing mowing and tilling the crimson clover after it has set seed. They are also studying pH ranges for the clovers, which prefer a higher pH than the blueberry cash crop.

Mutch and Michigan State researcher Rufus Isaacs are helping to elucidate other management aspects of clover cover crops, such as whether honeybees and native bees such as mason bees and sweat bees are attracted to clovers.

“The clovers work really well for blueberry production, rather than needing to fit system to cover crop. If you really want to do this, you can make it work,” says RJ.

—*Andy Clark*

thirsty legume, as well as field-scale equipment able to mow between several rows in a single pass (93).

Chemical suppression is unpredictable. An application rate that sets back the clover sufficiently one year may be too harsh (killing the clover) or not suppressive the next year due to moisture, temperature or soil conditions.

Partial rotary tillage. In a New York evaluation of mechanical suppression, sweet corn planting strips 20 inches wide were rotary tilled June 2 into white clover. Although mowing (even five times) didn’t sufficiently suppress clover, partial rotary tilling at two weeks after emergence worked well. A strip of clover allowed to pass between the tines led to ample clover regrowth. A surge of N within a month of tilling aided the growing corn. The loss of root and nodule tissue following stress from tillage or herbicide shock seems to release N from

the clover. Leaf smut caused less problem on the living-mulch corn than on the clean-cultivated check plot (170).

Crop shading. Sweet corn shading can hold white clover in check when corn is planted in 15-inch rows and about 15 inches apart within the row. This spacing yielded higher corn growth rates, more marketable ears per plant and higher crop yields than conventional plots without clover in an Oregon study. Corn was planted into tilled strips 4 to 6 inches wide about the same time the clover was chemically suppressed. Adapted row-harvesting equipment and handpicking would be needed to make the spacing practical (139).

Healthy stands can produce 80 to 130 lb. N/A when killed the year after establishment.

Unsuppressed white Dutch clover established at asparagus planting controlled weeds and provided N over time to the asparagus in a Wisconsin study, but reduced yield significantly. Establishing the clover in the second year or third year of an asparagus planting would be more effective (312).

Other Options

Seed crop should be harvested when most seed heads are light brown, about 25 to 30 days after full bloom.

Intermediate types of white clover add protein and longevity to permanent grass pastures without legumes. Taller ladino types can be grazed or harvested. Living mulch fields can be overseeded with grasses or other legumes to rotate into pasture after vegetable crops, providing IPM options and economic flexibility.

COMPARATIVE NOTES

- White clover is less tolerant of basic soils above pH 7 than are other clovers.
- In a Wisconsin comparison, ladino clover biomass was similar to mammoth red clover when spring-seeded (402).
- White clover stores up to 45 percent of its N contribution in its roots, more than any other major legume cover crop.
- Ladino and alsike are the best hay-type legumes on poorly drained soils.
- Spring growth of fall-seeded white clover begins in mid-May in the Midwest, about the same time as alfalfa.

Seed sources. See *Seed Suppliers* (p. 195). 🌱

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Vegetables

Beans  Read more...	Broccoli  Read more...	Cabbage  Read more...
Carrot  Read more...	Celery  Read more...	Cucumber  Read more...
Leek  Read more...	Lettuce  Read more...	Onion  Read more...
Pepper  Read more...	Potato  Read more...	Strawberry  Read more...
Tomato 		

Get A Nutrition Plan

COVER CROP N CALCULATION

What cover crop did you plant?

How much plant material is in a given area (lb/ac)?

$(C \times 43,560) / (A \times B)$ _____ (D)

How many places did you collect a square of plant material from?

_____ (A)

How big was the square, in ft²?

_____ (B)

How much did all of the plant material weigh combined, once dry?

_____ (C)

How much nitrogen is in that material (lb N/ac)?

D x given percent from the table below _____ (E)

How quickly will the material decompose and be available for plants?

Will you leave it on the surface?

E x 0.4 _____ (F)

Or will you incorporate (till) it?

E x 0.5 _____ (G)

Do you need extra nitrogen?

H - F or H - G _____

How much N does your crop need?

_____ (H)

COVER CROP	EXAMPLES	%N
Legumes	Hairy vetch Clovers Pea Sunn hemp	4% at flowering 3% is seeds are maturing
Non-legume grasses	Rye Oat Sorghum sudangrass	3% at flowering 2% is seeds are maturing
Non-legume broadleaves	Buckwheat Tillage radish Canola	Similar or a little less than grasses

CALCULATING MINERALIZABLE SOIL N FROM SOM

What % SOM does your soil test say you have? = _____ (A)

lb/ac of SOM (A) x 2,000,000 = _____ (B)

lb N/ac from SOM (B) x 0.07 = _____ (C)

lb mineralized N/ac/yr (C) x 0.02 = _____

COVER CROP COMPARISON CHART

Species	N fixer	N scavenger	Biomass (adds OM)	Weed Suppression	Beneficial Insects	Seed (lb) per 1,000 ft ²	Seed (lb) per acre	Seed Cost (\$) per 1,000ft ²	Seed Cost per acre	Reference cultivar	Reference Seed Source
Winter Rye		x	x	x		4	60 - 120	10	\$		
Oat		x	x	x		4	110 - 140	11	\$\$		
Sorghum sudan-grass		x	x	x		1	40 - 50	13	\$\$		
Hairy vetch	x				x	1	25 - 40	10	\$\$		
Chickling vetch	x				x	2	70	6	\$		
Sunn hemp	x		x			1	40	8	\$\$	8118	Fedco Seeds
Field pea	x		x	x	x	3	120	12	\$\$\$	4010 organic field pea	Johnny's Selected Seeds
Red clover	x			x	x	1/2	5 - 15	5	\$	mammoth red organic	Johnny's Selected Seeds
Crimson clover	x				x	2/3	22 - 30	6	\$		
Fava beane	x					5	200	20	\$\$\$	WW4403	Territorial Seed Co
Cowpea	x			x	x	5	100	17	\$\$	iron & clay	Johnny's Selected Seeds
Soybean	x					4	150	13	\$\$\$	viking 2265 organic	Johnny's Selected Seeds
Tillage radish		x	x	x		1/2	8-10	6	\$		
Buckwheat		x	x	x	x	2-3	50-90	7-10	\$\$-\$		
Oilseed rape		x		x	x	1	5-15	6	\$		