CONTENTS

Introduction 1

Why The Bed Flip is a Challenge in No-Till and Low-Till Systems 4

Removing Crop Residue Without Tillage 6

Preparing the Soil for the Next Crop 8

Amending the Soil Without Tillage 10

Seeding and Transplanting Tricks 11

Relay Cropping and Intercropping 12

Transitioning After Cover Crops 13

Planning a No-Till Crop Rotation 16

Conclusion 19

Resources 20

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No-Till Bed Transitions for Vegetable Crop Rotations

Preparing for a bed flip at his farm in central Kentucky, Jesse Frost rakes a bed clean after removing residue from the previous crop. *Photo courtesy of Jesse Frost*

USING YOUR CROPLAND EFFICIENTLY IS AS valuable to profitability as it is to soil health. When a growing area sits empty, you're not just losing out on possible revenue, you're also depleting your soil. This is as true on a half-acre, biointensive market garden as it is on a 12-acre specialty crop farm.

For farmers who use diverse crop rotations and no synthetic herbicides, one of the main periods when fields sit unused is during the transition from one crop to another. During this transition, often referred to as a "bed flip," it is common to simply mow a crop after it has finished producing and then till the residue into the soil. In this approach, it can take a few weeks before the crop residue decomposes and the soil is ready for planting again.

At the same time, the damage that tillage does to soil health is well known (see the sidebar, "What Is Wrong With Tillage?"). Using no-till practices during crop transitions or bed flips helps you to solve both of these problems at once. The transition can happen more quickly, allowing you to grow more crops each year, and it can be done in a way that supports soil health. That said, the practices can be complex. They also might require new equipment or methods that don't always feel intuitive. Despite the challenges, many farmers have adopted these practices, built upon them, and made them fit the unique context of their farms.

On our one-acre, intensive vegetable farm in central Kentucky, we've been farming with no-till practices for 8 years. Before that, we relied heavily on tillage for many years. Now that we aren't using tillage on every bed anymore, the change in both our lifestyle and enjoyment of the work has been significant. We're no longer cultivating until dark, fighting mud in the rainy seasons, or stressing about weeds, soil moisture, and crop health.

Instead of mowing a crop, tilling it in, and waiting a couple of weeks to replant as the residue breaks down, in the no-till method, a new crop is slotted in right away, without tillage and without waiting. This

The author's one-acre farm in Kentucky no longer uses tillage during bed transitions. Here, a cover crop will be flattened and killed with a tarp before the next crop is planted. *Photo courtesy of Jesse Frost*

fast transition or flip from one crop to another can have these additional benefits:

- less risk of soil erosion, or loss, because you're removing these short fallow periods
- more profit potential because you're growing more crops from the same space
- fewer weeds in the bed or row because you're managing the space more closely

What Is the Goal of No-Till?

Words like "low-till" or "reduced tillage" describe systems that may use tillage only sometimes, or ones that only use surface tillage. Some growers even think of some reduced tillage methods as "no-till" when they're only working the top 2 inches or so of soil, or aren't inverting or flipping the soil. The exact wording is less important than the overall goal. **In no-till, reduced tillage, and low-till production, the goal is the same**. It is to always keep the soil:

WHAT IS WRONG WITH TILLAGE?

When you till crop residue into the soil, you can harm the soil in a few ways. First, tillage equipment can destroy the soil structure and increase erosion. Tillage also kills worms, fungi, and other important forms of soil life. It can also cause weed problems in two ways. One is by bringing fresh weed seeds to the surface, where they will start growing. The other is by chopping and spreading the rhizomes, or underground stems, of perennial weeds.

Tillage destroys soil organic matter over time. Soil aggregates are tiny bundles of organic matter that are wrapped in inorganic soil particles and held together by plant roots and fungi. Aggregates are important because they hold water and nutrients in the spaces between them. Tillage breaks up soil aggregates and exposes organic matter to soil microbes, which break down the organic matter immediately. Because tillage brings oxygen into the soil, bacteria multiply quickly and decompose fresh crop residue as well as older organic matter.

The porous, crumbly structure of healthy soil is easily destroyed by tillage. *Photo by Jesse Frost*

This breakdown of soil aggregates can lead to compaction, or soils that are too dense for healthy crop growth. The space between soil aggregates is called soil pore space. It lets water soak into the soil and air to move through it. This is also the space where crop roots grow. In fact, 50% of the soil is not solid but pore space, filled with air and water! Tilling breaks the soil aggregates into smaller and smaller pieces, and the pore space shrinks. This creates compacted soils, and water, air or roots may have trouble entering.

Building soil health takes time and effort. But you can easily undo a lot of your hard work when you till a bed and keep it out of production for a few weeks. Also, there are no crops to feed the soil microbes through their living roots and photosynthesis during that time. This means no new organic matter is formed, and no crops are growing to help the farm business.

Permanent beds allow no-till growers to limit compaction to the walking paths between them. *Photo by Jesse Frost*

- covered as much as possible
- planted as much as possible (with a diversity of plants), and
- undisturbed as much as possible

These are the three main principles of conservation agriculture, and they're also the driving philosophy of no-till systems. The bed flip practices described here aim to meet these principles, while also honoring the "as much as possible" idea within each one. This is because no two farms are the same and every grower has to make the best decisions they can based on their context—including their weather, crops, soils, markets, capacity, tools, tolerance for risk, and so on.

Also, note that throughout this publication we use the terms "bed" and "row" interchangeably. No- and low-till growers generally prefer to use permanent or semi-permanent bed systems because the compaction from traffic (both footsteps and tires) will stay in the same pathway areas season after season. However, the ideas covered here can apply equally to row crop farmers, as well as farmers who grow in semi-permanent bed systems.

This publication will cover some of the tools and methods for no-till and low-till bed flips in organic and non-herbicide systems. First, we will discuss some of the most common challenges when starting out with no-till. Next, we will share tips for the key stages of a bed flip in these sections:

- Removing Crop Residue Without Tillage
- Preparing the Soil for the Next Crop (i.e., weeds, compaction, irrigation, and tilth)
- Amending the Soil Without Tillage
- Seeding and Transplanting Tricks
- Relay Cropping and Intercropping
- Transitioning After Cover Crops (termination strategies)
- Planning a No-Till Crop Rotation

This bulletin offers an overview of key ideas and practices for no-till systems. In order to start using no-till on your farm, you will probably need to consult with Extension specialists, experienced farmers, and more targeted publications. Cover crop management, soil fertility, irrigation systems, and the use of composts are all examples of important topics that we will outline here, but will likely require more research from you before you put no-till into action. See the Resources section for a short list of helpful publications, including *The Living Soil Handbook*, an in-depth look at no-till farming by the author of this bulletin.

Why The Bed Flip is a Challenge in No-Till and Low-Till Systems

IN THE SIMPLEST TERMS, "NO-TILL" MEANS NOT inverting the soil layers, because this disturbance can harm the soil, especially when done excessively. However, it's not always clear how to avoid tillage when transitioning between crops, and this is often the main question that experienced farmers have when they start to explore no-till. Fortunately, there are a number of proven practices to choose from, which are easy to implement with a little experience and forethought. Table 1 summarizes the most common practices and systems used in no-till bed flips, which we'll discuss in more detail throughout this publication.

Table 1. Some Common No-Till Systems and Practices

Deep compost mulching	A layer of compost is spread several inches deep over a semi-permanent bed system to suppress weeds, and provide both a planting medium and fertility.
Deep mulching	Brown material, such as straw, hay, and/or leaves are layered over a semi-permanent raised bed to suppress weeds and retain moisture.
Lasagna mulching	A mix of straw and compost are layered to create both a mulch and self-feeding planting surface.
Shallow till method	Thick, 1–2 inch applications of compost are worked into the top 2–3 inches of soil, creating a fine, plantable tilth on the surface, but leaving the root zone undisturbed.
Cover crops	Tall cover crops are grown to a mature stage before they're pressed to the ground to act as a mulch. Non-chemical termination is done either with crimping machinery, tarps, or cold weather.
Hybrid systems	Combinations of no-till systems are very common. A grower may use cover crops for mulching long-season transplanted crops such as tomatoes, and deep compost mulching for directly seeded crops.
Broadforking	This tool can break up deep compaction without heavy disturbance of soil aggregates. It's used by many no-till producers and is largely considered an acceptable tool for improving soil health with minimal disturbance.
Intercropping (or interplanting)	When two crops are planted in the same area at the same time. These crops typically belong to different crop families but can be the same family in certain situations.
Relay cropping	When a new crop is planted into a bed with an existing crop before it has been harvested.
Tarping	Large, opaque tarps are often used to control weeds and kill cover crops. By cutting off sunlight to the soil, seeds will germinate but then die. Existing plants will eventually die from the heat and lack of sunlight. This is most suitable for small scales.
Tilther	A tool that acts like a small tiller to lightly work the surface of the soil down to no more than 3 inches. It creates a plantable bed surface and works in amendments. It is often run with a power drill.

Table 2. Crop Termination Methods

Cut at soil surface to terminate	Cut slightly below surface to terminate	Terminated by harvest (the root mass is removed)
Arugula	Basil	Beets
Baby greens	Bok choy	Carrots (cut missed plants below the surface to terminate)
Borage	Beans	Garlic
Cilantro	Broccoli	Kohlrabi
Corn	Cabbage	Leeks
Cosmos	Celery	Onions
Cucumbers	Chicory	Potatoes
Dill	Collards	Radishes
Eggplant	Fennel	Sweet potatoes
Lettuce	Kale	
Mache	Mustard	
Marigolds	Parsley	
Melons	Rutabaga	
Nasturtiums	Spinach	
Okra	Swiss chard	
Peas		
Peppers		
Pumpkins and winter squash		
Summer squash		
Sunflowers		
Tithonia		
Tomatoes		
Watermelon		
Zinnias		

In order to maintain healthy, living soil in a no-till system, you'll need to develop strategies for specific crop transitions based on the habits of the preceding crops.

No matter how you transition to a new crop, you must terminate the previous crop during this period so that it doesn't become a weed. Exactly how you do so depends on the crop (see Table 2).

Certainly, if you're removing a crop entirely from the soil during harvest, such as beets, carrots, or potatoes, then the transition to the next crop is fairly straightforward. You harvest the crop, pull out any weeds, amend the soil as needed, and then plant the next crop immediately.

But for a lot of crops it's not so simple. For example, some crops leave behind a lot of residue you have to deal with, such as sweet corn or okra. Other crops will stubbornly continue to grow from their roots even after you've cut them close to the ground, such as kale or chicory. In order to maintain healthy, living soil in a no-till system, you'll need to develop strategies for specific crop transitions based on the habits of the preceding crops. For more, see the section, "Removing Crop Residue Without Tillage."

Amending the soil is another area where reduced tillage systems get complicated. How do you amend a soil without working in your amendments? There are technical and equipment-based answers to this question, as well as some philosophical ones. To that point, you may ask if there is ever a place for any amount of disturbance when transitioning from crop to crop. In fact, a small amount of disturbance, say to create a nice tilth in the top 2–3 inches of soil, can be efficient for you and easy on the soil's health, which we'll discuss in more detail in the section "Amending the Soil Without Tillage."

Having a plan for the leftover crop residue is an important part of a bed flip. *Photo by LD Productions*

Removing Crop Residue Without Tillage

DURING OR AFTER HARVEST, THERE ARE TWO MAIN types of residue to manage in a no-till bed flip: the aboveground residue (leaves, stems, etc.) and the belowground residue (roots, tubers, etc.).

With several options for its removal, the aboveground residue is generally less complicated to manage. For instance, you can use a knife or loppers, or even simply twist certain crops by hand to break them from the majority of their root system before removing them. Mowers are also an option, such as a push mower with a bag or a higher powered flail mower, sometimes referred to as a mulching mower.

Setting a flail mower low so the blades are just skimming the surface can terminate crops that are readily killed when cut at the soil surface and lightly prep the bed at the same time. This can make the bed flip incredibly efficient. Take lettuce for example: A flail mower that is set low cuts the lettuce crop right at the soil surface, thus terminating many lettuce varieties, but also stirring up the surrounding soil (note that some lettuce varieties may survive being cut this way). You'll need to rake the surface to remove the residue and check for any plants that survived, but you can sow a new crop almost immediately into the bed. Ideally, you'd keep a separate flail mower for this process, as the light amount of contact the blades make with soil will dull the mower faster than simply using it to cut crop material.

The blades of this flail mower have been set low so that it can be used to mow crops that die when cut close to the soil surface. *Photo by Jesse Frost*

A sharp harvest knife is a useful tool for removing an old crop from a bed while leaving its root system in the ground. *Photo by Jesse Frost*

As for managing the cut residue, some no-till producers leave it in the pathways or bed tops, in cases where it's tender and decomposes easily, such as leafy greens; other farmers will take all of the plant matter to the compost pile to increase their compost quantities. Composting the plant matter can help retain more of the organic matter that's lost when the material is mowed, left on the soil surface, or tilled in. That said, for some growers, leaving the material on the surface or in the paths will be the more efficient option, and the remaining matter still acts as food for soil microbes to slowly break down over time. Also, some growers use tarps or landscape fabric to speed up the decomposition. For instance, once a bed of arugula has been exhausted, they may mow the arugula, add a thin layer of compost, soak the bed, and then cover it with a tarp or landscape fabric. After a hot, sunny week, you can remove the tarp and the bed will be ready to replant.

With all approaches to residue management, check if signs of any plant diseases are present. Whenever possible, avoid leaving diseased plant residue in place. Depending on the disease, plants should be removed for active composting or discarded away from crop ground.

In a no-till bed flip, the roots stay in the ground. That's the goal—we do our best to leave the roots intact and in the soil as much as possible to serve as long-term soil food. By not chopping them up and whipping oxygen into the soil with a tiller, the root residue doesn't lock up nitrogen as it would if you tilled it into the bed. When roots are left intact, both decomposition and nutrient release are much slower, and this makes nutrients available for the next crop. Slowly decomposing roots also contribute to the soil's organic matter content and microbial health.

Any sort of soil disturbance should be done thoughtfully, with an eye on the weather to avoid erosion. It's preferable to avoid disturbing even a few inches, but sometimes that will be required for improving soil tilth (as discussed below) and/or to terminate the previous crop. Although not preferred, with more stubborn plants that regrow readily from their roots, you may be better off removing the entire plant, roots and all, or simply accepting a small amount of regrowth from the previous crop that's relatively easy to kill in the next crop.

Crop removal can be quite labor intensive, so it's ideal to combine this task with another job such as harvesting, when possible. Again, this isn't a concern for root crops, because harvest and removal are the same. But for other crops, how to do this is less obvious. When harvesting heads of broccoli, for example, you can first remove the entire plant by cutting it at the soil surface, leaving the root in the soil. You would then remove the head for harvest and place the stem in a cart or wheelbarrow, or leave it in the path for later retrieval or mowing. Similarly, during the final picking of bush beans, one person or crew can remove the whole plant at the soil surface and harvest in the shade while others flip the bed for the next crop.

During this bed flip, lettuce plants are cut at the surface, put in a wheelbarrow, and taken to a compost pile. *Photo by Jesse Frost*

It won't always make sense to do crop harvest and residue removal at the same time. Also, it can increase the amount of labor needed for a bed flip compared to a tillage system. However, when it's possible to harvest and remove the crop residue simultaneously, you're shortening the time between crops—potentially by weeks—which can extend the season and increase overall revenue.

These lettuce plants show three ways to remove a crop and the amount of root mass that is removed with each one: cut out (left), twisted out (middle), and pulled out (right). *Photo by Jesse Frost*

Preparing the Soil for the Next Crop

A stirrup hoe can kill weeds and help create soil tilth during a bed flip. *Photo by Jesse Frost*

When preparing a bed for the next crop, you must contend with the belowground biomass, as well as both the firmness of the soil surface and weeds. Fortunately, there are techniques and tools to help mitigate any challenges. Here we'll discuss weed management, compaction, irrigation, and soil tilth.

Weed Management

Once you've removed the previous crop from the bed or row, you need to evaluate a few things. The first is weed pressure. You must manage weeds before you plant anything else. Perhaps that will require a stirrup hoe, or another sharp cultivation tool capable of severing the plant from its roots. Then, rake off the weeds or carry them to the compost pile. Vigilance in this process will ensure a better transition to the next crop.

Unlike crop roots—which you can often keep in the soil—the roots of most weeds must be removed to reduce their potential for regrowth. Weeds that grow from rhizomes (or underground stems), such as johnsongrass and bermudagrass, are difficult to deal with in a no-till system, just as they are in a tillage system. Without tillage or chemicals, you'll need to remove these weeds by hand, which can be labor intensive. On the plus side, you aren't making the problem worse by chopping and spreading the rhizomes of your problem weeds, which tillage does. So these weeds become easier to manage over the long term in no-till systems.

Compaction

The second factor you need to evaluate is compaction. Compacted soil is one of the most significant limiting factors in production. Deep layers of compaction prevent water and air (oxygen, carbon dioxide) from moving in or out of the soil, and this creates anaerobic layers that are unfavorable for healthy plant roots and microbial populations. Living plants, along with the remaining roots of previous crops, will help to address compaction over time. But some direct action may be needed in certain soils, at least in the beginning years.

Tools like the penetrometer will give you exact compaction readings, but for the average grower, the simplest way to evaluate compaction is with a 0.5 inch (or larger) medal rod or piece of rebar. Although not precise, if you gently force this tool into soil it will give you some indication of your compaction levels. Try this method when the soil isn't too wet or dry. If the rebar sinks into soil to a depth of around 14 inches with no more than your own body weight, there is likely little compaction in the rootzone, and you can move on to your next step.

If you can't press the rebar into the soil easily, then you may need to address the compaction. But first, note that rockier soils can complicate simple compaction tests like these. Visual cues may be more helpful in rockier situations. In this case, take a 1-foot deep cross section of the soil with a shovel and examine it. You're looking for a loose crumby structure versus a dense structure without holes, which might signify compaction.

To address compaction, consider adding compost to the top of the bed, then lightly broadforking or

While not as exact as a penetrometer, a metal rod or piece of rebar can give you a quick idea if your soil is compacted or not. *Photo courtesy of Jesse Frost*

Compacted soil (left) is dense, has no holes, and becomes hard when it dries. Healthy soil (right) has a loose structure and large holes, and remains crumbly when it dries. *Photos by Harold van Es*

subsoiling the area. Allow the compost to fall into the crevices that you create as you fork the bed. This will slowly decompact the soil. You shouldn't need to do this every year, although some soils are simply going to be denser than others and will require a longer period of intervention.

Irrigation

In any production system, both seeds and new transplants require moisture to germinate, grow, and thrive. Irrigation is one area that might be a little more difficult with certain no-till systems. For example, in a deep compost mulch system, the compost can be hydrophobic, which means it resists absorbing water after it dries out. This is typical of chunkier composts that haven't been heavily sifted. Beds in this condition will therefore require more irrigation to meet the crop's needs. Alternatively, mix compost with water-retaining soil particles by lightly working it into the 1–2 top inches of soil. This light tillage of the surface will increase the water holding capacity of the compost. Drip irrigation is less effective in deep compost mulch systems when plants are newly transplanted or are directly seeded. This is because the water tends to drop straight through the compost, whereas on a bare soil surface it spreads out more. Overhead irrigation is often preferred for establishing crops. Avoiding chunkier composts, or screening them out, can likewise reduce the risk of hydrophobic surfaces.

In growing conditions where water is limited, a light "tilthing" of the top 2–3 inches of the soil to mix in some soil particles will aid in moisture distribution and retention (as described in the next section). However, it's important to remember that even small amounts of disturbance lead to a greater potential for weed seed germination—if the soil surface is better for germinating crop seeds, it's better for weed seeds too!

Soil Tilth

The third factor to consider is the soil's tilth, or the plantability of the soil surface. The soil surface can become compacted or simply firm, and this makes sowing or transplanting quite difficult. In this case, you may need some amount of light surface disturbance. In order to achieve good tilth, you can use a simple hoe or other light cultivation tool. To break the surface, you can use something like a tilther as well, which is a very shallow tillage tool run off of a power drill. On larger scales, perhaps use a harrow, a power harrow, or a tiller set extremely shallow (around 2 inches deep), preferably with a precision depth roller attachment that manages the depth. The idea is to simply break up the surface compaction to make transplanting or seeding easier and more effective. Before the tilth is fully addressed, it's important to examine options for amending the soil without deep tillage.

A tilther can be used to prepare a bed for planting, with little soil disturbance. Its action also helps to work amendments into the soil. *Photo by Jesse Frost*

Amending the Soil Without Tillage

MAKING SURE THAT THE SOIL IS ADEQUATELY fertilized for each crop is essential. At the same time, fertility management is complicated in any system, and this is especially true in a no-till system because you are not adding amendments to the soil when you are tilling.

In no-till management, growers must rely on soil biology to help pull nutrients in the soil, and some specific techniques are described below. A full discussion of soil fertility management is beyond the scope of this publication. Always consult with an agronomist and/or refer to soil test results before amending soil.

Fertilizing without tillage requires good planning, a couple basic tools, and some creativity. That said, it can be as simple as applying the desired nutrients in dry form before addressing the tilth, and then using a cultivation tool or shallow tillage tool to lightly work them in. In a situation where you don't need to address the tilth, you can add amendments to the surface and then rake them in or run them over with a seeder to press them below the soil surface, where they won't blow away or dehydrate in the sun (liquid fertilizers are discussed below).

There are also attachments for seeders, for example Earthway and Jang (among others), that allow you to "sow" dry, granular amendments into the soil without disturbing its surface. When you use this approach at planting, you're able to add amendments near the seeds and deeper into the soil. You can also use it to sidedress a crop later on. These fertilizer attachments are also helpful when you're using relay cropping or intercropping strategies, as a way to fertilize the soil without removing the previous crop. See the next section, "Relay Cropping and Intercropping."

A broadfork can be used to both loosen compacted soil and incorporate amendments. *Photo by Jesse Frost*

Fertigation is an option for amending soil in no- and low-till bed systems. Essentially, this technique involves adding amendments to your beds with your drip irrigation system during crop growth, as opposed to adding a dry form before planting. This approach allows you to avoid soil disturbance while also fertilizing a long-season crop throughout its life. Fertigation usually requires a special injection system, and it's used most commonly for nitrogen, although you can apply many macro and micronutrients this way.

However, fertigation systems can be expensive, and may not make sense in every context or for every crop. As a result, growers use them most often in high tunnels, where regular fertilization is required for the intensively planted "heavy feeders" that we often grow in covered culture, such as tomatoes, cucumbers, peppers, and eggplants. Ultimately, if you're considering a fertigation system, you'll need to consult with a specialist on the details of system design and cost before moving ahead.

Many no- and low-till growers use thick layers of compost to act as a mulch, growing medium, and fertilizer. Weed pressure is generally low in deep compost mulch systems (sometimes called a "no dig" system), so the rules of a bed flip are generally the same—clear the previous crop, leave the roots in the soil, address compaction, and so on. However, the compost itself often provides the tilth and fertility, meaning that it acts as a mulch, a loose planting surface, and a hardy supply of nutrients all at once. Compost mulches can have their own complications, especially in terms of nutrient management, but they can also save time in both crop removal and replanting, as the tilth is built into the medium itself. Also, the compost will turn into healthy soil over time.

As outlined in the previous section, the process of decompacting the soil is another point where you can partly or fully address fertilization. Specifically, an option is to use a tool such as a broadfork to both loosen compacted soil and incorporate amendments at the same time. While this technique puts amendments deeper into the soil, it can also result in uneven distribution of nutrients. So when compaction isn't an issue, it's better to use one of the other incorporation techniques described above.

Seeding and Transplanting Tricks

PLANTING THE NEXT CROP DURING A BED FLIP CAN be pretty straightforward, but there are a few tactics to ease this transition even more.

Planting in straight, consistent rows is important. Especially if using a bed system, plant crops in an even grid. This makes it easier to avoid planting a new crop directly into any roots that are left in the ground, as you'll know where they are and can simply plant between them.

Rotating to a crop that's grown in a different row spacing than the previous crop can help avoid root residue. For example, if you have a bed of lettuce growing in four rows, that leaves three empty rows in between where you can plant the next crop and avoid residual lettuce roots. So in this case, you might follow with something like chard or kale, which is generally planted in two or three rows.

Though not a necessity, when rotations are thoughtfully designed like this, you can harvest or mow the lettuce, dig a furrow between the rows of lettuce, and insert the transplants of the next crop between the rows, with almost no time between crops. The furrow isn't always necessary, but if you don't have an easy way to create the tilth (like a power harrow or tilther) then quickly cultivating with a stirrup hoe or digging a furrow with a hoe can be an effective means of creating a plantable bed surface between rows of the previous crop.

Residual roots can be more challenging when directly seeding a crop. One workaround is to use a seeder with a double disc opener versus one with a shoe. The tip of the shoe is likely to catch on the remaining roots and create issues, whereas the double disc opener on the Jang or Hoss seeder, for instance, can slice right through small roots. Small gaps may exist where the seeds land on the roots, but depending on the crop, this won't have a significant effect on yield.

Planting in a grid lets you plan for the next crop so that you are not planting into old roots. For example, the stars show where you could plant 3 rows of a crop like beets or kale, in between the 4 rows of lettuce being planted now. *Photo by Jesse Frost*

Another way to ease the challenges of seeding in a no-till bed flip is to simply cut the previous crop out lower than you normally would to terminate it. This way there's less root interference near the surface. However, some crops, for instance celery, develop significant root systems near the surface, and in cases like this it simply may not be ideal to follow up with a directly seeded cash crop.

These are some examples of what to consider during crop planning. Though you can come up with standard operating procedures, many crops will have their own guidelines based on how it is easiest to terminate them.

This double disc opener attached to a seeder helps with seeding into crop residue. *Photo by Jesse Frost*

Relay Cropping and Intercropping

In this example of relay cropping in a high tunnel, carrots were sown on bed edges in January, with tomatoes planted in the center in April. *Photo by Jesse Frost*

In this example of interplanting, 30-inch beds include lettuce and onions on the edges, with peppers in the center. *Photo by Jesse Frost*

RELAY CROPPING IS ONE PRACTICE THAT COMBINES bed flipping with efficiency. Relay cropping is when you plant the second crop while the first crop is still growing, similar to passing the baton in a relay race. An example of this is planting an early spring radish and leaving enough room in the center of the bed for a summer planting of peppers just before the radishes come out. The peppers establish as you're harvesting the radishes. Then you can even sneak in a round of lettuce where the radishes were before the peppers really start producing.

Relay cropping, and intercropping in general, requires significant knowledge of crop growth habits, but it can help to maximize your space, especially with longer season crops that are slower to mature. Also, these practices require good weed control to be successful.

Using these practices can easily add complexity to a crop rotation. See the section "Planning a Crop Rotation" for tips on how to make relay cropping and intercropping a little easier to plan for.

A cover crop of crimson clover was sown under a fall crop of radicchio. *Photo by Jesse Frost*

Planting Cover Crops

You can use relay cropping to include a cover crop in your rotation as well. This is particularly helpful for growers who otherwise might not be able to plant a cover crop, for example if you're trying to maximize production because you operate on a very small scale, or you're in a region with a short growing season. Also, for late, long-season crops like peppers, tomatoes, okra and the like, you can relay a cover crop into the soil beneath the crop before the first frosts of the season come.

For example, you can sow crimson clover underneath a fall brassica or chicory crop a few weeks before a frost, and then water it well to ensure germination. The fall crop can continue to grow into the colder months, while the winter cover crop establishes and gets ready to take over the bed for the winter.

In terms of winter cover crops, annual clovers are well suited for this job because their small seed means they germinate more reliably when you sow them onto the soil surface. Other species of cover crops work well as long as irrigation is adequate, including rye, vetch, oats, and winter wheat. I would recommend lightly cultivating or raking the seeds in before irrigation to improve germination and avoid seed predation from birds. In cases where undersowing doesn't make sense it may be better to simply take the previous crop out like any bed flip and then sow the cover crop.

However, if you want a winter-killed cover crop but the previous crop hasn't finished producing, it's generally best to sow them four weeks before the first frost, or even earlier in colder climates. Frost-hardy cover crops, like peas and oats, will need several hard freezes before they winter-kill (28ºF and below). In climates where freezes are infrequent, use warm-season cover crop species in the late fall. In this case, you want to get good seed-to-soil contact to ensure the cover crop germinates and grows significant biomass. One way to do this is with a seeder that you run carefully beneath the existing crop. But to avoid damaging foliage, it's best to do this before the plants have taken over the bed, or at the end of the season for crops like peppers that should be tall enough to allow room for a seeder.

Relay cropping requires knowledge of crop growth habits, but it can help to maximize your space.

Transitioning After Cover Crops

TRANSITIONING FROM A COVER CROP TO A CASH crop can be complicated, depending on the scale. Although this is a bigger topic than we can fully cover here, there are some basic techniques that growers can use to terminate winter hardy cover crops and plant cash crops rapidly and successfully.

First, to achieve the best results with them, cover crops require excellent soil preparation, the right seed selection, and good conditions for both germination and growth. Weeds can become an issue if you haven't managed them well before you plant a cover crop. If the cover crop doesn't thrive, the next crop won't either, so you should treat cover crop plantings like cash crop plantings to ensure success and adequate biomass.

Also, it's important to note that the cover crop must die in order to plant another crop into it. Whatever cash crop you aim to plant into that area shouldn't have to compete with the cover crop for water, light, and nutrients. Rather, the cover crop should slowly be offering its nutrients to the cash crop over the season, as it decomposes.

This concept is also true when planting a cover crop in a relay planting. Although the young cover crop will not be offering nutrients yet, you will want to time its planting so that it does not grow too quickly and overcrowd the cash crop during its most productive period.

Here are a few common methods for terminating cover crops, along with considerations for planting a spring crop into their residue.

Winter-Killed Cover Crops

Assuming you have the right climate for it, selecting cover crops that will winter-kill can be a straightforward option. As long as the winter-sensitive crop was planted early enough to produce sufficient biomass, it

Tomatoes transplanted into a mowed cover crop of rye and vetch. *Photo by Jesse Frost*

To kill this cover crop of rye and vetch, first it is mowed and then covered with a tarp. *Photo by Jesse Frost*

will die and mulch the surface over the winter. Aim for a planting date of roughly 3–4 weeks before the first frost, but you may need more time in a cooler climate or less time in a warmer one. In the spring, the resulting mulch can simply be raked aside and planted without much need for soil preparation or fertilization, depending on the crop. Field peas and oats are the most common combination for winter termination, though above zone 6, oats may not reliably terminate during the winter. Neither crop will reliably terminate in areas that don't reach 28°F or below multiple times in a winter. If a pea cover crop doesn't terminate, mowing it low to the ground similar to other crops can be adequate, making it a low-risk winter cover crop, even in slightly warmer regions.

These farmers are using a t-post to flatten a cover crop before placing a tarp over it. *Photo courtesy of Jesse Frost*

Tarping

On a small scale, it's relatively easy to smash down a cover crop in late spring or mid-season using whatever is on hand, such as a barrel, fencepost, a t-post strapped to your feet, etc., and then cover it with a black tarp for a few warm weeks to terminate it. The cover crop should be smashed all in the same direction, and laid flat against the ground as much as possible so that its residue is easier to manage and seed into.

When using a tarp, the cover crop will die off after a few warmer weeks, then larger plants like eggplant, tomatoes, or peppers can easily be inserted into holes dug in the cover crop residue. You can also mow the cover crop before tarping it, which can give a slightly better mulching effect. This is because mowing spreads out the mulch more uniformly rather than laying it flat, where gaps can allow for weeds to emerge. Importantly, if the weather is cold or the sun isn't out, the tarp won't be as effective as it will be in warm conditions.

There are a few other potential downsides to consider with tarping. The time a plot spends under a tarp represents a gap in production, just like tilling a

bed and waiting for residue to decompose. Also, while tarping can be an effective practice on a smaller scale, at larger scales, it can become unreasonable from both an economic and environmental standpoint due to the amount of plastic required.

Roller Crimpers

The roller crimper is another way to terminate some cover crops, such as a winter hardy rye. However, timing is critical: The cover crops should be fully at flowering stage for the crimping to be effective. Every cover crop is a little different, but flowering is when the crop is most vulnerable to termination through crimping. This is because their stems are easier to break. The seeds are viable once the seed heads have filled out and hardened, so be careful to not miss the window for crimping. If you're not using a tarp, then plant rye without vetch, as vetch won't terminate as easily with crimping alone. Crimson clover can terminate more readily with the rye than hairy vetch, as do Austrian winter peas and lacy phacelia. It is important to be familiar with the success of roller crimping in your area too. In some places, especially those with low rainfall, cover crops will not produce enough biomass for crimping to be effective.

Roller crimpers are more popular among organic farmers because they offer non-chemical termination. Larger-scale units are 8–10 feet wide and tractor-mounted, but smaller ones are available for small tractors or for walk-behind machines like BCS tillers. Walk-behind roller crimpers can also work inside high tunnels, although this can be a little difficult depending on the high tunnel's design. If you want to invest in this equipment for use in a high tunnel, first make sure you have the required entry and exit space. The edges of raised beds can also be a little tricky with roller crimpers on a small scale. If not using raised beds, however, the roller crimping method could be a viable option.

Using either a roller crimper or a tarp will give you a thick mulch layer. Sowing vegetable seeds into this dense mulch generally requires specialized equipment, such as no-till seed drills and transplanters, which is how larger-scale growers would address this challenge. Specialized seed drills cut through thick mulches and deposit seeds in tiny furrows they create. Likewise, specialized transplanters can cut a small furrow where crew members drop in transplants, before the implement closes the furrow. On a small scale, you'll need to perform these tasks by hand for the most part: moving aside the residue, digging holes, fertilizing lightly if needed, and then inserting transplants.

With cover cropping, start small before investing too heavily in the equipment required for larger scales. See if you can add it to your crop rotations and that it makes sense for the timing of your plantings, as cover crops like rye often aren't ready to terminate until well into the spring. The soil beneath them will also be cooler, pushing the season back in some instances. Growers should be exceedingly thoughtful when using cover crops, as they can become a weed if not properly terminated. Consult with local experts on cover crop selection and management, and visit www.sare.org/cover-crops.

With cover cropping, start small before investing too heavily in the equipment required for larger scales.

This rye cover crop was crimped and then terminated with a tarp. *Photo by Jesse Frost*

Planning a No-Till Crop Rotation

Planning no-till crop rotations can be complex at first, but over time many farmers settle on approaches that work for them. *Photo by Jesse Frost*

USING THE NO-TILL STRATEGIES OUTLINED IN THIS publication to make bed flips faster and increase production can get confusing when it comes time to plan your crop rotations. To make bed flips efficient, no-till crop planning needs to consider three variables:

- the rotation of crop families
- the row spacing of different vegetables
- the compatibility of crops used for intercropping

A mix of grass and legume cover crops are growing beneath rows of okra and in the walkways to improve soil health. *Photo by Jesse Frosty*

Of course, when you make a no-till rotation plan, you will always want to remember how crop rotation is necessary for disease control in certain crops, as well.

Rotating by Plant Family

Growers often divide beds into plant families, with heavier feeding crops like nightshades or cole crops followed by something that isn't as heavy feeding, like lettuce, carrots, green onions, etc. To keep it simple, oftentimes you'll grow one crop in the plot before flipping it all at once to the next crop. But, this sort of simple rotation can be thrown off when you're attempting to do a bed flip using no-till practices, where keeping every bed planted is a core principle.

To illustrate, let's say a grower's typical crop rotation includes a plot dedicated to spring brassicas, followed by another vegetable crop family such as lettuce. Since this grower wants to maximize growing space, they perform a no-till bed flip as the individual brassica beds finish. This means some of the beds will go earlier into the second crop, lettuce, and possibly finish earlier.

When you stagger bed plantings this way, it creates more complications but also more opportunities, because you aren't waiting for the first crop to finish entirely before planting the second one. It can also create production gaps of its own, because the first wave of lettuce beds you planted (the second crop) might finish when there's still time left in the fall to

Figure 1. Sample 8-year rotation with cover crops

	January	February	March	April	May	June	July	August	September	October	November	December
Year 1	Peas (cover crops)		Broccoli			Lettuce		Beets		Rye + Vetch (cover crop)		
Year 2	Rye + Vetch (cover crop)			Summer Squash			Green Beans			Rye + Vetch (cover crop)		
Year 3	Rye + Vetch (cover crop)				Tomatoes + Beets (intercrop)		Tomatoes		Peas (cover crop)			
Year 4	Peas (cover crop)		Onions				Lettuce		Rye + Vetch (cover crop)			
Year 5	Rye + Vetch (cover crop)					Winter Squash			Peas (cover crop)			
Year 6	Peas (cover crop)			Potatoes			Buckwheat (cover crop)		Garlic			
Year 7	Garlic						Buckwheat (cover crop)		Kale			
Year 8	Crimson Clover (cover crop)				Peppers + Romaine (intercrop)		Peppers				Peas (cover crop)	

This is a sample of what an 8-year rotation with cover crops might look like. This example is from the author's farm in central Kentucky (USDA hardiness zone 6b). Adjust crop durations and planting times for your climate.

grow something. You can account for this in the crop rotation by adding either a third crop to those beds that finish early, or a quick, easily terminated cover crop, like buckwheat or cowpeas. Figure 1 provides an example of an 8-year rotation that I might use for a bed on my farm in central Kentucky.

Row Spacing Patterns

It's helpful to consider the planting pattern of different crops when planning them in a sequence. In the "Seeding and Transplanting Tricks" section we gave the example of following a crop that's planted in four rows with one that's planted in 2–3 rows, to avoid the issue of planting into old roots. When using a bed system, you can also use row counts to plan for faster transitions through the use of relay cropping. For example, if you started with a crop planted in four rows, later in the season you could relay plant a three-row crop in between the four rows. We'll discuss these strategies in more detail in the next section.

Tips for Relay Cropping and Intercropping

Planning can become very complicated when you use intercropping and relay cropping in a rotation. This comes down to the fact that a bed will often have two crops in it at the same time instead of just one, sometimes from different families. There are a few ways to handle this complexity.

Green onion transplants will go into composted beds on the left, with lettuce planted to the right. Both crops are planted in a grid pattern to help ease the no-till flip to the next crop. *Photo by Jesse Frost*

In time, farmers find consistent rhythms and systems that work for their context.

An early season crop such as carrots or spinach is being sown on the edges of this bed. Later, tomatoes will be transplanted in the middle as a relay crop. *Photo by Jesse Frost*

As with any crop rotation, you shouldn't follow one crop with another from the same crop family to avoid disease issues. But, you can use relay cropping or intercropping to add more of the same crop family in the same bed at the same time. This makes crop planning easier by eliminating the need to plan for other crop families. It can work so long as all the other parameters for good production are met, including moisture, fertility, bed preparation, and timing. So if a plot is for brassicas, then you can sow turnips together with a longer season brassica like cauliflower. Other examples include planting lettuce beneath sunflowers, or beets next to chard. The biggest challenge with this strategy is figuring out the timing so that one crop does not overtake another. However, competition is a challenge with intercropping whether or not the crops are in the same family, and a good understanding of each crop's growth habits is essential.

Combining different crop families in a bed is also an option, such as planting cilantro in the bed space next to tomatoes. But a grower will still need to follow the important principle of planting a different crop family in the next phase of the rotation. So in this case, make sure the next crops that go into these beds aren't in the tomato (solanaceous) or cilantro (apiaceae) families. If it's a heavy feeder like broccoli, good options for relay crops include lettuces, spinach, and carrots, as long as space allows. Relay planting requires you to spend more time in the crop planning phase.

Intercropping and relay cropping are concepts that could easily get someone's head spinning. Something vitally important to keep in mind is to ease into these ideas over the course of several seasons. Start with small trials with the easiest crops, such as planting lettuce on the sides of tomatoes or peppers. This way, building out a crop plan for more intensive production that includes intercropping and relay cropping can happen slowly and naturally over time. In short, there's no rush, but hopefully the idea of bringing more crops out of the same space per season is attractive enough to give it a shot. In time, farmers find consistent rhythms and systems that work for their context.

Likewise, it's okay to look for alternative ways to keep beds covered in between crops, for example through the use of mulches, cover crops, and even tarps, especially as growers figure out ways to incorporate more cash crops. When you look at the three main principles of no-till (keep the soil covered, planted, and undisturbed) they always end in one key phrase: as much as possible. We want to maximize the space we have as growers, but sometimes what makes the most sense for our gardens, our markets, or even our sanity, is to simply mulch an area until the next crop is ready to be planted. That is also perfectly acceptable, especially if you're doing what you can to preserve soil health as much as possible.

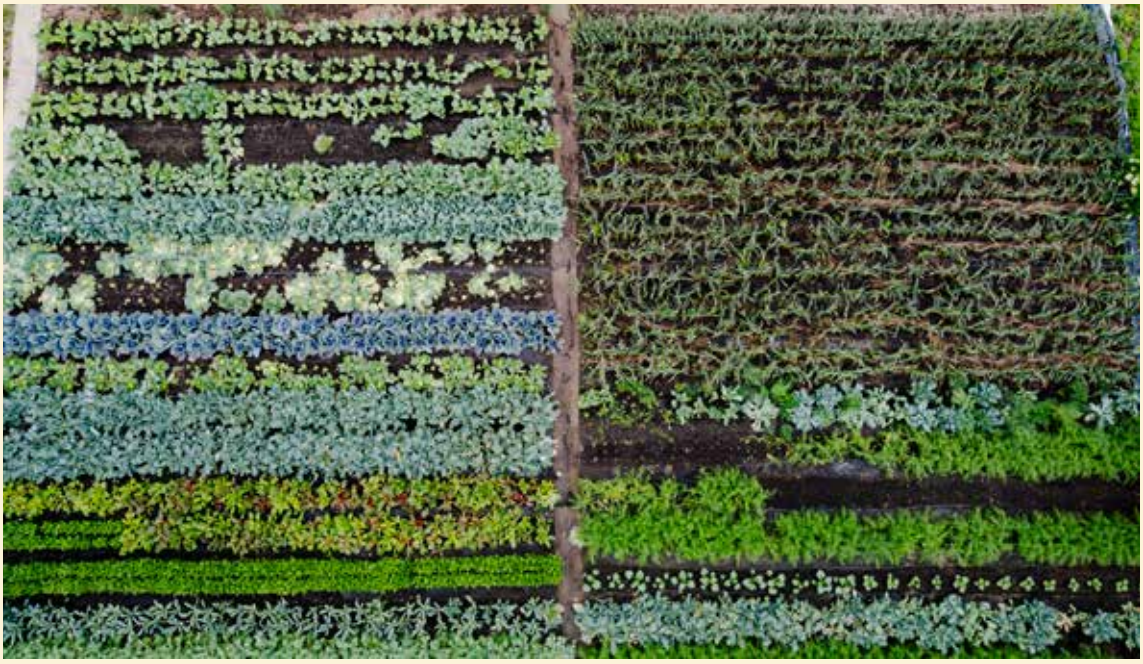
Conclusion

WITHOUT QUESTION, THERE ARE COUNTLESS BED flip situations that growers could run into over the course of their careers. For that reason, the goal of this publication is not to give the answer to every situation, but to provide a framework you can use to find a solution in *any* situation. With that in mind, the room to innovate in this space is as infinite as the number of situations that could arise.

Take baby greens for example. Where many growers may resort to tilling in a crop of baby arugula once it has finished producing, growers like Ray Tyler of Rose Creek Farms in Selmer, Tenn., found that they could simply mow the crop, cover it with compost, saturate the bed with water, and leave it under a sheet of landscape fabric for 1–2 weeks and return to a clean and enriched planting surface. This approach might not get another crop into that space as quickly as, say, hoeing out all the tiny roots, but it's a process that fits his farm's system and clears the bed with less labor compared to a quick transition. Tarps and landscape fabrics not only keep the soil in place, they also germinate weed seeds while allowing organic matter to slowly decompose. Growers like Ben Hartman at Clay Bottom Farm in Goshen, Ind., have been experimenting with burlap as an alternative to plastic in some situations and although it doesn't have the same suffocating effect of plastic, perhaps it could stand in for landscape fabric after the bed flip of baby arugula described above.

Of course, soil health is the goal, but you have to balance this against business health as well. For example, several years ago I visited Sage Hill Ranch Gardens in Southern California. While there, farmer Spencer Rudolf demonstrated for me a bed flip with his two employees. They twisted the lettuce out of the bed, with an equal focus on both speed and leaving as much root as they could. It was a compromise because twisting the crop out left behind less root matter than bringing a knife to the field, but it was faster. This technique met his needs as a business owner—to maximize the growing space while reducing the amount of time spent on removing the crop residue and not dramatically compromising soil health.

So, the hope is that this publication has provided you tools and techniques to utilize on your own farms that will speed up your production a little bit, create healthier soil, and hopefully add to both your overall profitability and production along the way.



Intensive no-till production at Wild East Farm in Marion, N.C., has resulted in healthier soils and better quality produce that is in high demand among local consumers. *Photo by LD Productions*

Resources

This represents only a partial list of the many resources available online on the topic of no-till vegetable production. Consult with local Extension specialists and experienced farmers for more support.

The Living Soil Handbook: The No-Till Grower's Guide to Ecological Market Gardening

www.notillgrowers.com

This book offers an in-depth look at no-till practices in vegetable production, by the same author of this bulletin. The website also includes many stories about farmers' experiences with no-till.

Cover Crops for Sustainable Crop Rotations

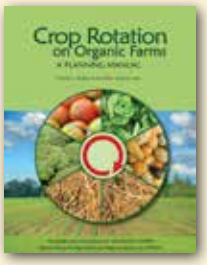
www.sare.org/cover-crops

An online collection of resources related to cover crops. From here you can find SARE books on the subject of cover crop management, as well as links to regional cover crop councils.

Building Soils for Better Crops, 4th Edition

www.sare.org/bsbc

This book includes comprehensive information on soil management, including soil fertility, cover crops, composting, and more.



Crop Rotation on Organic Farms

www.sare.org/resources/crop-rotation-on-organic-farms

This manual provides an in-depth review of the applications of crop rotation-including improving soil quality and health, and managing pests, diseases, and weeds.

This bulletin was written by Jesse Frost. SARE would like to thank Kristy Borrelli (SARE), Jermaine Hinds (SARE), Katja Koehler-Cole (University of Nebraska-Lincoln), and Eric Nordell (Beech Grove Farm) for their valuable contributions. It was produced by Sustainable Agriculture Research and Education (SARE), supported by the National Institute of Food and Agriculture (NIFA), U.S. Department of Agriculture under award number 2022-38640-37487. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the USDA.

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