

Steps Toward a Successful Transition to No-Till



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THE NO-TILL REVOLUTION

No-till is revolutionizing farming worldwide. In the United States, more than 60 million acres, or 23 percent of the total, were planted no-till in 2004, compared to 38.9 million in 1994 (Fig. 1). No-till is practiced by grain, dairy, hog, poultry, and vegetable farmers. Farmers with large and small operations are accepting no-till as a beneficial cropping system. Growers adopt no-till to increase their efficiency and profitability, and to improve their environmental stewardship.

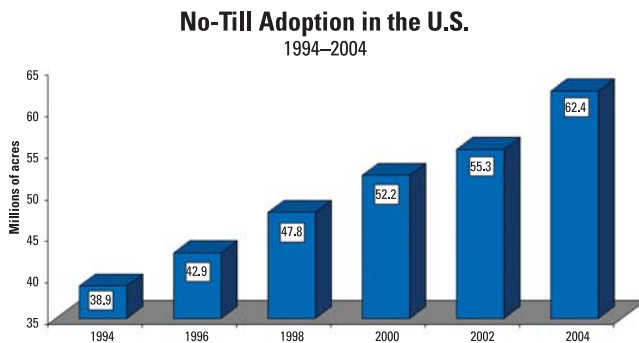


Figure 1. No-till adoption in the U.S. (CTIC, 2005). No-till adoption continues to rise, representing almost 23 percent of the nation's cropland today. Source: Conservation Technology Information Center.

1. INCREASED EFFICIENCY.

Eliminating tillage allows farmers to plant their crops in a more timely fashion. The time savings come at a busy time of the year when the opportunity cost of labor is high. In addition, farmers can frequently combine individual contour strips or other small fields when practicing continuous no-till systems while maintaining excellent erosion control. The benefits of increased planting, spraying, and harvesting efficiency and reduced yield losses from field edges lead to greater efficiency.

2. INCREASED PROFIT.

No-till is more profitable than tillage systems, even if yields are the same because costs are reduced. First, tillage equipment and its maintenance are eliminated. Typically, the no-till grain farmer needs only a planter (and/or drill), a sprayer, and a combine for field crop production. Second, fuel costs are reduced, as well as tractor horse power requirements. Third, labor costs are reduced. In some cases, no-till allows farmers to grow more corn in their corn/hay rotation while continuing to maintain excellent erosion control. There are also added costs to no-till, such as a burndown herbicide application. However, the additional costs are small compared to the savings. No-till farmers also experience greater profits because they can manage more acres than a tillage farmer.



As shown in these photos, no-till is used by small and large farmers to improve their efficiency, profitability, and environmental stewardship.



Soil tillage consumes time, steel, and fuel.



Soil tillage is a major cause of soil erosion.



In no-till, soil is protected from erosion by mulch cover.

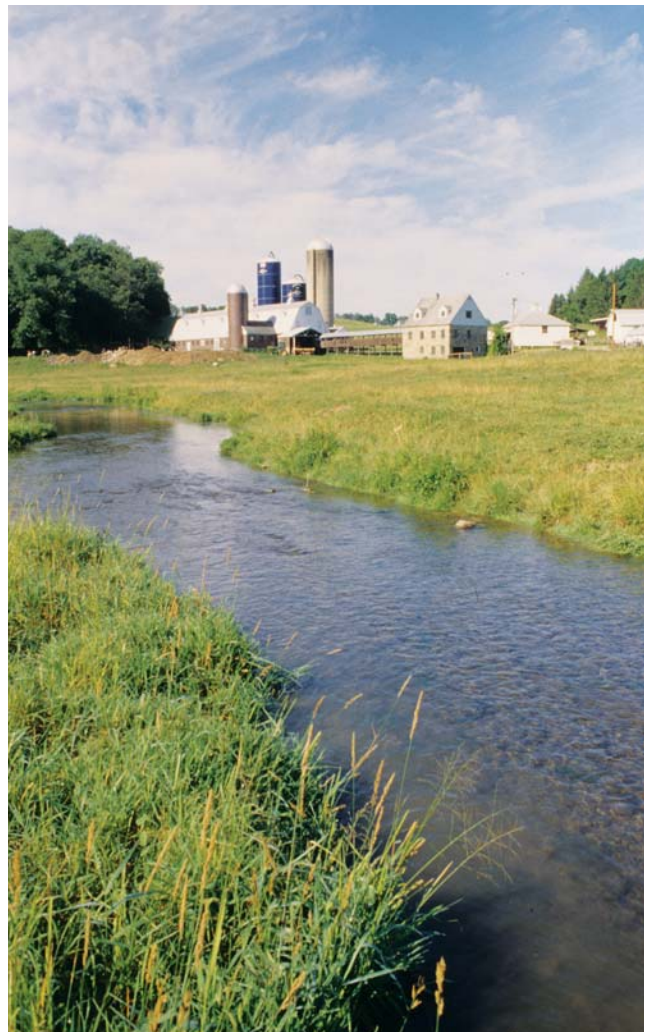
3. IMPROVED ENVIRONMENTAL STEWARDSHIP.

No-till is an environmental best-management practice because soil erosion and runoff are dramatically reduced and water infiltration, soil organic matter content, and soil biological activity are increased.

Whereas the expansion of no-till is impressive, most American farmers still till their soil. In Pennsylvania, 75 percent of annual crops are still planted with tillage. However, there is a new interest in no-till, among producers as well as policy makers and the general public. Every year there are farmers who convert part or all of their planted acres from tillage to no-till. In this publication we give producers and agricultural service personnel advice for making this transition successful. When we use the term no-till, we refer to a long-term cropping system with maximum residue cover and essentially no soil disturbance. Tillage can only be used very sparingly and should do minimal disturbance to residue cover and the soil profile.

Generally, this tillage is accomplished using specialized equipment designed specifically to be used in no-till planting systems for the following purposes:

1. injection or shallow incorporation of manure
2. establishment of cover crops
3. to address specific compaction concerns.



No-till planting systems improve water quality and help to increase ground water recharge.

Planning the transition to no-till

Advance planning is the key to a successful transition to no-till. It is important to realize that no-till is more than just planting with a no-till planter or drill. It has implications for soil sampling, soil fertility management, variety selection, manure handling, weed management, and harvesting, to list just a few. Thus, we need a systems approach to no-till, giving consideration to all aspects of the farming system that will be affected by a conversion to no-till (Fig. 2). A beginning no-tiller has to learn quite a few new skills. In this publication we point out key differences between no-till and tillage systems. We also discuss which conditions under no-till are more challenging for the farmer and which are less challenging.

A beginning no-tiller is advised to start learning about no-till on a few fields where conditions are most conducive to success. No-tilling in more challenging conditions should be saved for later. It is also recommended to get help from experienced no-tillers or agricultural professionals who are knowledgeable about no-till. To be well prepared, we recommend you start planning for the transition at least 9 months before establishing your first no-till crop. This will help you make a long-term commitment to no-till, working out challenges in the system as you learn about this exciting farming practice. So let us start with the first step in transition, which is to plan for crop rotations and cover crops.



When starting to no-till, it is essential to learn from experienced no-tillers, for example, at field days.

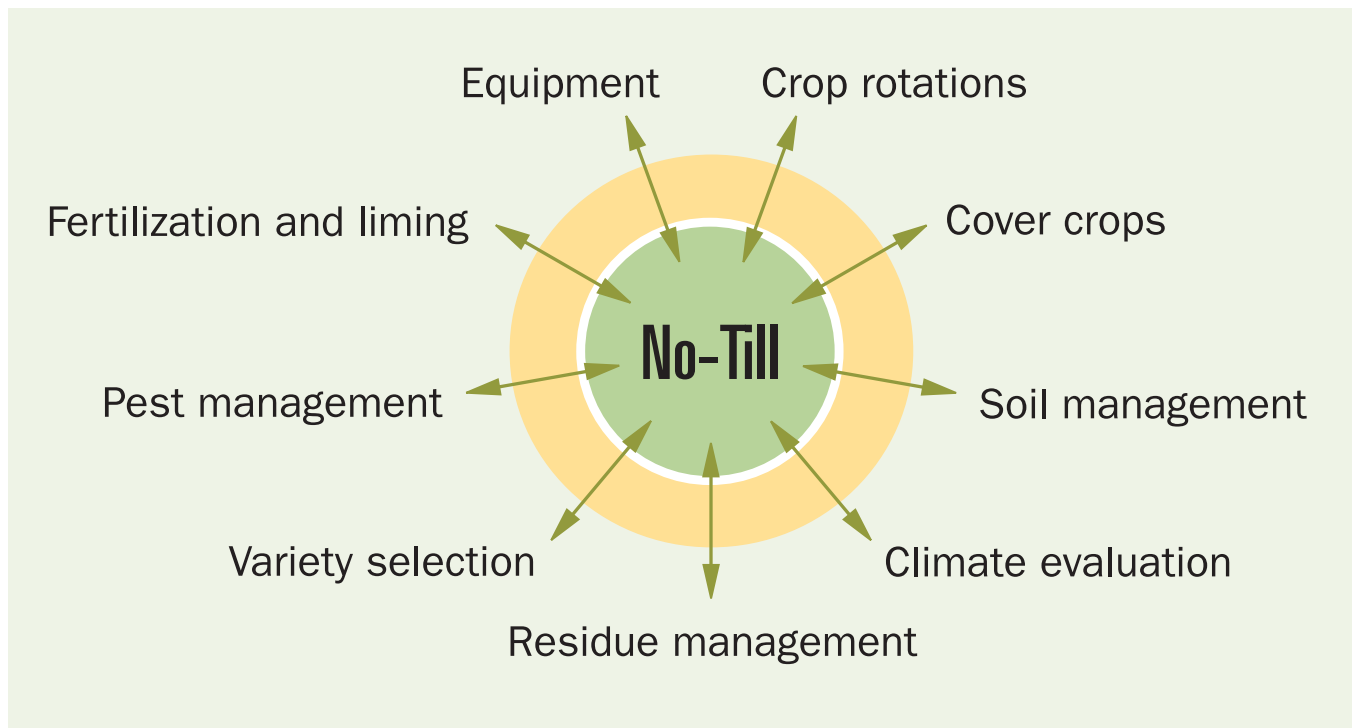


Figure 2. No-till requires a systems approach.

STEP 1: CROP ROTATIONS

Reasons for crop rotations in no-till

Crop rotations are more important in no-till than in conventional till systems. Table 1 compares corn yields for no-till and tilled systems with and without rotations. In addition to yield increases from rotations, the following benefits are described.

1. PROVIDE SUFFICIENT SOIL COVER.

No-tillers have to “think soil cover.” Most agronomic benefits of no-till result from the presence of crop residue at the soil surface. Ideally, we recommend 50 percent soil cover or more at all times. Unfortunately, some crops leave very little crop residue behind, leading to minimal residue cover in no-till. Examples are corn silage, alfalfa killed after the last cutting in the fall, and soybeans. Other crops, such as corn or small grains, leave large amounts of residue behind, some of which lasts for two years. Corn residue, for example, will be found in the field two years after harvest under Pennsylvania conditions. Rotating high-residue with low-residue crops can therefore help to obtain sufficient cover because some residue from the high-residue-producing crop can carry over into the low-residue-producing crop. After the low-residue-producing crops, it is recommended to plant a cover crop to obtain sufficient cover in the following crop.

2. FACILITATE SOIL WARMING.

Slow soil warming in no-till can sometimes reduce corn yields. Research has shown that slow soil warming in



Crop residue cover is essential in no-till.

Table 1. Crop rotation is more important in no-till than in tillage systems. Yields were increased 17 bu/A owing to rotation in no-till, versus only 8 bu/A with conventional tillage achieved over a 20-year period on a poorly drained soil in Ohio.

	No-till	Conventional till
Continuous corn	112	125
Corn-soybean rotation	129	129
Corn-soybean-meadow	127	133

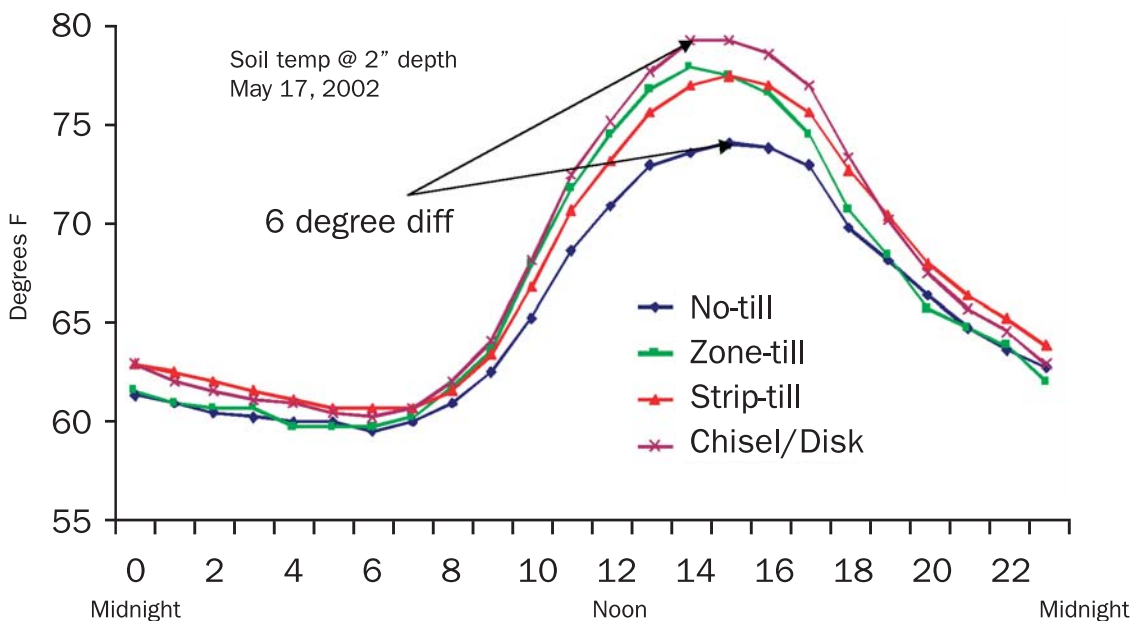


Figure 3. Comparison of soil temperatures for no-till and other tillage systems.

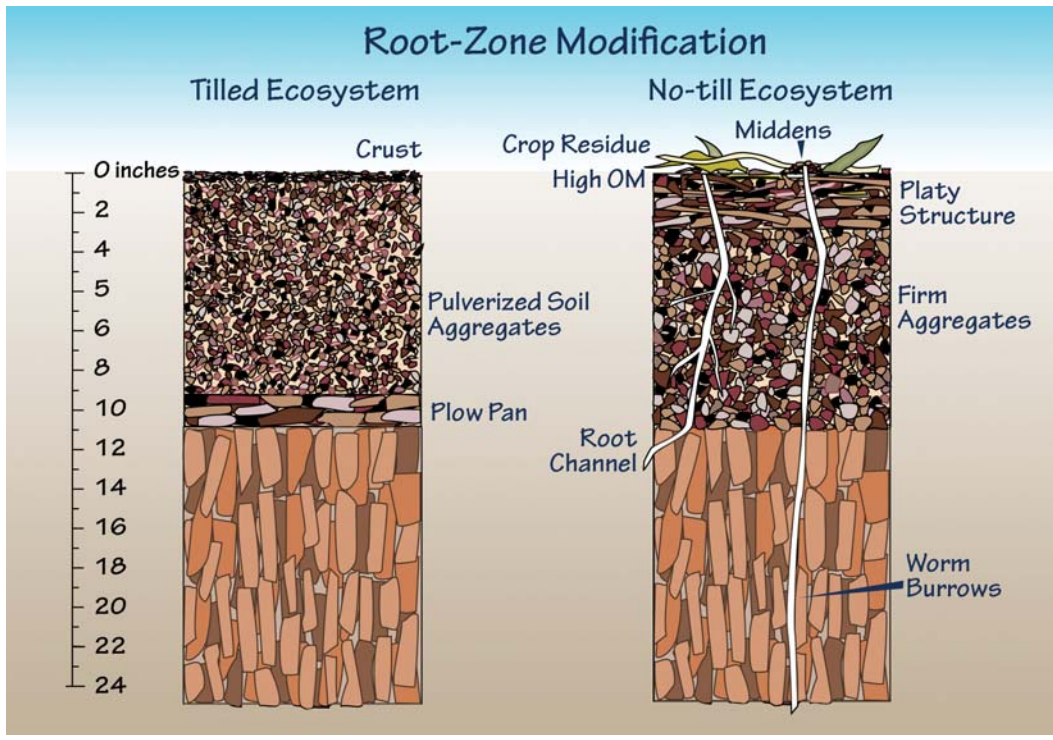


Figure 4. In long-term no-till, the soil profile changes compared with a tilled soil profile.

no-till corn after corn harvested for grain can reduce yields compared to tilled corn if the growing season is shorter than 2600 growing degree days, or if the soil is poorly or somewhat poorly drained. Figure 3 contrasts soil temperature using no-till and other commonly accepted tillage systems with continuous corn. If corn is rotated with low-residue producers such as soybeans or sod, this problem is avoided. Thus, you must seek a balance to provide sufficient soil cover while at the same time achieving early-season soil warming.

3. STIMULATE BIOLOGICAL ACTIVITY.

In no-till, the farmer has to work with nature, not against it, to obtain optimum soil conditions for the crop. The no-tiller relies on soil organisms such as bacteria, fungi, mycorrhizae, arthropods, earthworms, and plant roots to obtain those optimum conditions. Continuous soil cover and absence of soil disturbance is beneficial for many soil organisms. Besides that, it is beneficial to provide the soil biological community with a “balanced diet” consisting of a mix of crop residue types. For example, it is beneficial to rotate crops with a high C/N ratio (e.g., corn or small grain residue) and a low C/N ratio (e.g., soybean residue or manure). It is also advantageous to mix crops with different root systems so different parts of the soil are explored. Deep taproot systems such as those of alfalfa or red clover can complement the extensive, fine root systems of crops such as rye, wheat, and corn. Deep taproots

Table 2. Nitrate-N lost from three different tillage systems in continuous corn and corn-soybean rotations.

	Moldboard plow	Chisel plow	No-till
	Lbs/A N loss with drainage water (lbs/A)		
Continuous corn	42	58	57
Corn after soybeans	25	32	21
Soybeans after corn	29	31	22

Source: Kanwar, R. S., T. S. Colvin, and D. L. Karlen. 1997. Ridge, moldboard, chisel, and no-till effects on tile water quality beneath two cropping systems. *J. Prod. Agric.* 10:227-234.



Earthworms are an essential part of a successful no-till system. This picture shows 17 earthworms in a 3 by 3 foot area on the Cedar Meadow Farm, owned by Steve Groff, no-till producer in southern Lancaster County.



Planting corn in soybean stubble is one of the easiest ways to start no-tilling. However, residue levels may be lower than desired.



No-tilling alfalfa after soybeans is an excellent option.

help create macropores in the subsoil, whereas fine roots work as nets that stimulate aggregation and improve soil tilth. Both types of root systems have their own beneficial effects on soil. Figure 4 provides a visual image of tilled and no-till ecosystem soil.

4. MORE EFFICIENT NUTRIENT USE.

Rotating grains with legumes is a sound agronomic practice that avoids unnecessary losses of nutrients and lowers the need for nitrogen fertilizer. One study showed that nitrate losses during winter were higher after continuous corn than after corn that was preceded by soybeans, whereas differences between tillage systems were not significant (Table 2). Rye or wheat grown after corn is an excellent option for taking up excess nitrogen in the fall and winter.

5. BREAK PEST AND DISEASE CYCLES.

Crop rotation is crucial in no-till to break weed, insect, and disease cycles. Certain perennial weeds that can become problems in no-till are avoided by using crop rotation. Crop rotation also promotes the use of different herbicide programs, thus avoiding the development of herbicide resistance in weeds. Covering the soil with a growing crop or cover crop at all times will also help reduce weed pressure. Some diseases and insects survive on residues of a specific crop, but if you rotate crops you can remove the threat of the insect pest or disease.

Where to start no-till crop rotations

In Table 3, we provide ratings for the ease of no-tilling a crop into a prior crop. This is provided to help new no-tillers pick situations that will be simpler when making the transition to no-till.

CORN

Corn is most easily no-tilled after fall-killed hay. Fall-killing helps to obtain a good kill of the sod. Low soil temperatures in the spring are less of a problem when corn is planted after fall-killed sod. The only note of caution concerns grubs, sod webworms, and wireworms that survive in sod. To avoid insect damage to corn after a sod, it is important to use an appropriate insecticide. If a fall-killed sod is composed of pure alfalfa, we do recommend planting a small grain cover crop in the fall to guarantee better soil cover in the spring.

Planting corn after soybeans has many of the same advantages as planting corn after fall-killed sod. Another option for no-till corn is to plant after a winter cover crop that was planted following corn silage. Beginning no-tillers are advised to kill winter cover crops before they are 12 inches high. No-tilling corn after corn grain becomes more of a challenge because of

Table 3. Ratings for the ease of no-tilling a crop into the residue of a prior crop.

Crop planted	Crop residue planted into (1 = least, 5 = most challenging)				
	1	2	3	4	5
Corn	Fall killed alfalfa or grass hay	Soybeans	Cover crop after silage corn	Corn grain	Spring killed alfalfa or grass hay
Alfalfa/grass	Corn silage	Soybeans (some residue may be removed)	Small grain	Corn grain (some residue may be removed)	
Soybeans	Corn grain	Double cropped after small grain	Corn silage + cover crop	Full season after small grain	
Winter small grain	Corn silage	Soybeans	Small grains	Corn grain	
Spring small grain	Soybeans	Corn grain	Corn silage		

cooler soil temperatures and because pests and disease cycles are not disrupted.

No-tilling corn after the first cutting of alfalfa or grass hay in the spring also presents difficulties. Compared with planting corn after fall-killed sod, the operator has to face these challenges: (1) seed placement is more difficult because the soil may be dry and hard after the hay consumed a lot of moisture and the soil has been packed by hay-making traffic; (2) corn germination and early growth may be limited because of low soil moisture content; and (3) inadequate kill of the forage may occur because little foliage is available to absorb herbicide after hay or haylage has been harvested.

ALFALFA AND GRASS FORAGES

The least challenging for no-till establishment is probably spring establishment of forages after corn silage, soybeans, or small grains where both grain and straw are harvested. We do recommend a fall cover crop that winter kills, such as oats, if spring planting into silage fields to provide adequate mulch. We also recommend removal of soybean residue in the spring prior to planting forages unless soybean residue is very well distributed. No-till planting forages in late summer after small grain is another excellent option as long as the straw has been removed. No-till helps conserve soil moisture and this rotation allows for excellent weed control options prior to planting the forage. Fields heavily infested with winter annuals may need to be sprayed in late fall.

The most challenging situation is to establish forages after corn grain or after small grain harvest where straw has been left in the field. The large quantity of corn stalks or small grain straw makes it almost impossible to obtain good seed depth control or seed-to-soil contact. You may therefore need to remove some of the residue just prior to planting. If the residue is not removed, one must pay attention to adequate down pressure and depth settings on the drill. Forages can be established with or without a nurse crop, but in no-till there is generally limited need for a nurse crop for erosion control. The most common error in planting forages, especially alfalfa, is to plant them too deep (see the *Penn State Agronomy Guide* recommendations). To avoid this, alfalfa seed can be dropped behind the opener disks but in front of the packer wheel.

SOYBEANS

Soybeans are the most common no-till crop in Pennsylvania. Yields of no-till soybeans tend to equal or exceed those of soybeans planted with tillage. There are a couple of reasons why soybeans are a favorite no-till crop:

1. Soybeans have the unique ability to branch out and thus compensate for poor seed spacing or occasional missing plants. This contrasts soybeans with corn, where uneven seed spacing promptly results in yield losses. Soybean seeds are big and not as sensitive to seed depth placement as some small-seeded crops such as alfalfa that are easily placed too deep.
2. Soybeans are less sensitive to the “cold soil syndrome” than corn because they are typically planted later and the growing point does not remain underground for long.
3. No-till weed control has been relatively easy in soybeans with the advent of Roundup-Ready soybeans.
4. No-tilling double-cropped soybeans after small grain harvest saves time and water, items often in short supply at this time of the year.
5. No-tilling soybeans may allow for earlier planting, which can help increase yields.

We rated soybeans as most suitably planted after corn because of the versatility of soybeans, and because of the erosion protection provided by the corn stalks. It takes two years for corn stalks to completely decompose, so corn residue provides soil cover for two years after it is harvested. This additional soil protection the year following soybeans in a corn soybean rotation is very important for erosion control, soil moisture conservation, and soil quality improvement.

Whereas soybeans are somewhat forgiving of a poor planting job, it is certain that improved seed spacing and proper planting depth will result in a better soybean crop. Planning for this optimal stand starts at harvest of the previous crop. It is important to guarantee even distribution of crop residue at soybean planting time, especially when drilling soybeans because no row cleaners are present to move residue out of the way. Proper adjustment of down pressure and depth on no-till drills is also critical for good results.

No-tilling soybeans after small grain harvest in the summer is a successful proposition in south-central and southeastern Pennsylvania. More than 60 percent of double-cropped soybeans are no-tilled to save precious time and water during the summer. This has also proven to be a good way to begin no-tilling. The largest challenge in no-till double cropping is to get adequate planter penetration in dry soil and to be able to see where the drill marks are when you are planting. Other successful options for no-tilling full season soybeans are after corn silage (winter cover crop is needed for adequate mulch) and the year after small grain harvest.

SMALL GRAINS

Winter small grains such as wheat, barley, or rye are ideal candidates to no-till after corn silage. The small grain can easily be drilled into the virtually bare soil. Planting small grains in the fall or spring into soybean residue is another good way to begin no-tilling. It is important to spread the soybean residue evenly. Small grains help to supplement low residue amounts following soybeans, which reduces soil erosion and retain soil moisture for the following crop. Planting winter small grains after spring small grains (preferably a different species) also works well. It is advisable to harvest some straw to reduce excessive residues at planting time.

Planting winter small grains after corn grain is the most challenging. It is recommended to wait at least a week after corn harvest to give corn residue a chance to dry. Uniform residue distribution is very important if the latter is attempted, and the drill needs to be able to plant through large amounts of crop residue.



No-tilled corn into hairy vetch seeded last week of August in oat stubble. Centre County, 2006.



No-till tobacco into rye cover crop after extreme rainfall events. Lancaster County, 2006.



Tobacco established in disked soil; note severe erosion. Lancaster County, 2006.



No-till alfalfa recently drilled into soybean stubble that was baled off in fall (previous year's corn residue still visible). Centre County, 2006.



New alfalfa stand established with no-tillage. Centre County, 2006.

STEP 2: COVER CROPS

Reasons for cover crops in no-till

1. PROVIDE SOIL COVER.

Cover crops are needed for successful no-till if residue levels are low or nonexistent. The goal is to keep at least 50 percent crop residue cover at all times. Examples of crops that leave insufficient residue are silage corn and soybeans. Even fall-killed pure stands of alfalfa may leave insufficient residue. Corn harvested for grain usually leaves adequate residue cover on the surface. Small grains also usually leave adequate residue cover, even if the straw is harvested, because of the close plant spacing and extensive tiller production. Cover crops especially suited to provide soil cover are small grains such as rye, wheat, barley and oats, and grasses such as ryegrass.



A rye cover crop planted after corn silage alleviates compaction, captures nitrate, and provides mulch.

2. CAPTURE NUTRIENTS.

Cover crops capture nutrients from fall-, winter-, or spring-applied manure and excess fertilizer from preceding crops. The cover crop takes up the nutrients that might otherwise be lost to ground- or surface water or to the atmosphere (Table 4). When the cover crop is killed, the nutrients are

Table 4. A rye cover crop reduced nitrate leaching after sweet corn and broccoli grown with three different nitrogen rates.

	Rye cover crop?		
	No	Yes	Reduction in N leaching
	Average winter N-leaching loss (lb/A)		%
No N applied	20	13	33
Half recommended N rate	35	23	32
Recommended N rate	63	36	42

Source: Brandt-Dohrn, F. M., R. P. Dick, M. Hess, S. M. Kauffman, D. D. Hemphill, Jr., and J. S. Selker. 1997. Nitrate leaching under a cereal rye cover crop. *J. Environ. Qual.* 26:181-188.

slowly released upon decomposition of the cover crop residue and roots. Fast-growing cover crops with fibrous and deep root systems should be chosen for removal of excess nutrients.

3. FIX NITROGEN.

Leguminous cover crops fix atmospheric nitrogen. If managed properly, legumes can fix up to 200 lb/A nitrogen between fall and spring in southeastern Pennsylvania. The prime leguminous cover crops are hairy vetch, crimson clover, red clover, and winter pea. Hairy vetch can survive the winter in most of Pennsylvania if established in August or early September. Crimson clover is less winter hardy, but it has been found to do well in southeastern Pennsylvania. Red clover

Table 5. Typical aboveground biomass production and nitrogen content of some cover crops and cover crop mixtures in southern Pennsylvania.

	Dry matter production non-legume (lb/A)	Dry matter production legume (lb/A)	Total nitrogen content (lb/A N)
Rye	5,000		50
Wheat	4,500		45
Barley	4,500		45
Hairy vetch		3,600	160
Red clover		2,500	91
Crimson clover		2,400	90
Hairy vetch/oats	1,700	2,700	119
Hairy vetch/rye	3,500	1,800	102
Hairy vetch/wheat	2,600	2,400	111
Crimson clover/oat	2,000	4,700	109
Crimson clover/sudax	2,500	3,600	106
Crimson clover/wheat	4,500	3,200	100

Source: Duiker, S. W., and W. S. Curran. 2004. Cover crops. Pp. 109-118. In *The Agronomy Guide 2005-2006*. Penn State College of Agricultural Sciences, University Park, PA.



Hairy vetch is a hardy annual leguminous cover crop that can fix substantial amounts of nitrogen.

needs to be established before July for good results. Winter pea can be established in the spring or in late summer after a small grain, but it will often winterkill in Pennsylvania.

4. PROVIDE WEED CONTROL.

Cover crops can reduce weed pressure. If the soil remains bare after harvest, some type of vegetation will eventually occupy that empty space. A farmer has no control over the types of plants that will invade. Some may become difficult to control in the next season's crop, whereas cover crops will be easier to kill. The mulch left by the killed cover crop will present a physical barrier for weeds.

5. IMPROVE SOIL.

Cover crops improve soil structure by adding below- and aboveground biomass that is converted into soil organic matter upon decomposition. Living roots act as nets, binding soil particles together in aggregates. Fungal hairs that live in association with plant roots (mycorrhizae) serve the same purpose. There are indications that crops such as sorghum-sudan grass and small grains, which produce an extensive, fibrous root system, are effective in breaking up compacted soils. Cover crops with a taproot (such as brassica species, e.g., rape or forage radish) can "drill holes" through compacted layers, creating channels for roots from other plants to grow into the subsoil. Table 5 provides information on biomass production and nitrogen content of cover crops commonly grown in Pennsylvania.

When crop residue decomposes the microbes release certain compounds that stimulate micro-aggregation of soil particles. This is a temporary effect that disappears when crop residue is degraded. It is more evident, but short lived, after crops that decompose fast, such as soybeans, hairy vetch, and

crimson clover. Fully decomposed organic matter, or humus, also contributes to aggregate stability.

Cover crop selection and management

Which cover crop is right for the situation depends on the purpose for using it, when it can be established, which crop was planted previously, and which crop will follow it. For a no-till farmer who has little experience with cover crops, it may be best to plant a small grain such as rye, wheat, or oats following corn silage and early harvested soybeans. Methods of establishment depend on equipment and time available, as well as the investment the farmer is willing to make. A no-till drill ensures the most consistent results and guarantees an optimal stand. Broadcasting seed on the surface with a spinner or by airplane is cheaper and quicker, but it produces less consistent results. A higher seeding rate is needed when broadcasting compared with drilling. The cover crop seed may also be broadcast on the surface and very lightly worked into the soil surface. Another option is to cover the seed with manure. The aim should be to achieve seed-to-soil contact without disturbing much crop residue or soil.

The cover crop may be fertilized with fertilizer or manure, but this is not necessary. The cover crop needs to be terminated in a timely fashion. Usually a burndown herbicide is necessary to kill the cover crop in no-till. Some cover crops such as oats and crimson clover may winterkill and die naturally. Some farmers are experimenting with rolling or mowing a cover crop to kill it at a critical time during its life cycle (usually late boot stage for small grains). Timing becomes very critical for success with this method, and flexibility with main crop establishment decreases. In addition, the cover crop will have produced a huge amount of residue that may make planting difficult and that can have an allelopathic effect on the following crop. Thus, a beginning no-tiller should kill most cover crops before they become too tall (about 12 inches).



Cover crop roots can help to alleviate soil compaction: both soil clods are from wheel tracks within 30 feet, the one on the left with, and the one on the right without, rye cover.

STEP 3: CLIMATE AND SOIL EVALUATION

Why do climate and soil matter in no-till?

A farmer who is starting no-till should evaluate climate and soils because some climatic and soil conditions are more favorable for no-till than others. Altitude and exposure are two factors that may affect temperature on a farm. No-till soils remain cool because of the mulch cover, which may result in slow germination and early growth of spring crops (particularly corn). If one can pick, it is advisable to start no-tilling at low altitudes and on southern exposures where temperatures are higher. The delay in early growth does usually not result in lower yields in no-till. Water savings during the summer give no-till a competitive edge over tillage that usually results in similar or higher yields at harvest time, despite slower early growth.

Cold soil syndrome in corn production

Slow warming of the soil in spring can be a problem for corn if it is planted after corn grain. This so-called “cold soil syndrome” is an issue primarily if the growing season is shorter than 2,600 growing degree days (GDD) for corn (north of I-80 and at higher altitudes throughout the state). Poorly and very poorly drained soils are also a challenge for no-till and are not the place to start. Thus the challenges of no-tilling corn after corn grain are greater in the northern parts of Pennsylvania, at higher altitudes, and where soils are more

poorly drained. A no-till management intensity map was created to give an idea where challenges are greatest (Fig. 5). Cultural and equipment solutions for cold soil syndrome and drainage problems include crop rotations, using row cleaners, zone- or strip-till, and artificial drainage. Corn after soybeans or sod suffers little from the cold soil syndrome. Row cleaners on the corn planter help move residue away from the seed zone, allowing sun rays to warm the soil. Zone-till results in a narrow strip (< 8”) being tilled to shallow depth (< 4”), allowing for quicker drying of the surface soil compared to only using row cleaners. Typically, zone-till is done with two or three fluted coulters mounted in front of each row unit on the planter.

Strip-till involves deeper tillage than zone-till with a chisel-like shank (more than 8”). As with zone-till, the area between the rows remains undisturbed, while the crop is planted in the narrow tilled strips. In addition to alleviating the cold soil syndrome, strip-till allows for deeper soil loosening, which may be an advantage in compacted soils. Strip-till is done with a unit that has shanks placed at similar spacing as the corn planter. It is performed as a separate operation and can be done in the fall or spring. Remember that all these “add-ons” to a straight no-till system cost money and reduce residue cover, which may have a negative effect on issues such as erosion control and water savings. It is important to follow

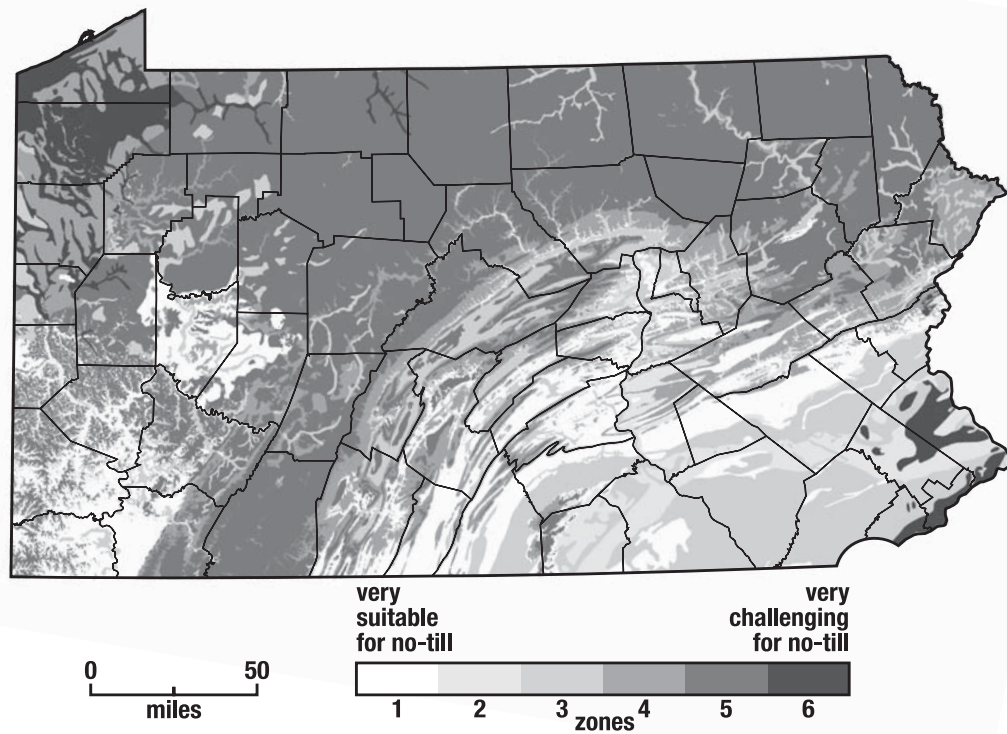


Figure 5. No-till management intensity zones for Pennsylvania. This map is relevant for corn planted into corn residue.



Strip-tillage is a vertical tillage operation consistent with no-till as long as more than 30 percent residue cover remains after planting.



No-till is an attractive option in stony soils.

the contour with in-row tillage practices because runoff can follow the cultivated, bare strips.

The final practice that can help alleviate the cold soil syndrome is artificial drainage. It is recommended on very poorly and poorly drained soils to allow quicker soil drying and warming.

Slope, stoniness, and soil depth

Slope, stoniness, and soil depth are other factors to evaluate when selecting fields for no-till. The steeper the slope, the stonier, and the shallower, the more attractive no-till becomes compared to tillage because of erosion control, reduced stone-picking, and water savings with no-till. In some instances where surface stones are a problem, no-tillers may use a mechanical rock picker to clean the surface prior to starting their no-till system. Sometimes it is not economical to plant row crops on these marginal lands, however.

Evaluate soil quality

If a soil is severely degraded because of intensive tillage, it may take a few years to get a successful no-till system started. The soil is, as it were, “addicted to tillage” and needs to improve through biological activity. This takes time. A beginning no-tiller should therefore start on soils of good quality. If these are not available, it is advisable to take measures to improve the quality of beat-up soils before transitioning to no-till. Use the Pennsylvania Soil Quality Assessment Card to assess the quality of your soil. You can also use the Soil Conditioning Index to evaluate the effect of different tillage and



Soil erosion on sloping cropland can be significantly reduced using no-till systems. Using no-till systems on sloping land can give the producer more cropping options.

cropping practices on soil erosion and soil quality. Contact your local NRCS office for assistance in the use of this tool.

STEP 4: CROP RESIDUE MANAGEMENT

Once you have selected fields for the transition to no-till, it is time to pay attention to residue management. This is one of the most important components of no-till. On the one hand, residue cover provides all the environmental benefits of no-till, such as erosion control, infiltration improvement, evaporation reduction, and soil biological activity. On the other hand, too much or badly managed residue can create big problems during no-till crop establishment.

The goal of residue management is to achieve uniform and adequate cover following harvest of the prior crop. Spreaders or choppers are available for all combines to achieve uniform residue distribution. Chaff spreaders can also help to spread fine materials that otherwise would be distributed directly behind the combine. One way to alleviate uneven distribution of crop residues is to maximize the cutting height, which will keep to a minimum the amount of residue going through the combine.

Non-uniform residue distribution results in uneven stands. The coulters or openers on the planter or drill will not cut through piles of residue, the bottom of which will usually be moist. This results in hair-pinning of crop residue and poor seed-to-soil contact. Depth placement will also be affected. Imagine, for example, that seeding depth is set at 2 inches. If the residue is 2 inches thick, the seed will be placed on the soil surface. In a pile of 1-inch-thick residue, the seed will be placed 1 inch below the soil surface. In a bare spot, the seed will be placed 2 inches below the soil surface. Seeds will then encounter different microenvironments, resulting in uneven emergence and early growth. Residue that is unevenly distributed can also lead to weed control problems because soil-applied herbicides do not reach the soil where residue is piled up. These situations will have a significant impact, especially on corn yields.



A residue spreader on the combine is essential for successful no-till. Shown are a batt spreader for large residue pieces and a chaff spreader for fine chaff.

Chopping crop residue after harvest redistributes residue somewhat, but it will never completely correct unevenly distributed residue. We do not normally recommend chopping crop residue because of the extra time and energy that are invested for limited returns. In fact, it is easier to plant through standing crop stalks that are still anchored in the soil than through a random collection of loose stalks, whereas soils will warm up and dry out sooner in the spring in standing residue. Standing stalks trap snow during winter and provide wildlife benefits. Chopped residue, on the other hand, decomposes more rapidly and is more likely to move with water and wind, all negatives for soil erosion protection and uniform mulch distribution. During the growing season the dead stalks fall over, providing the mulch protection desired. Once crop residue is unevenly distributed behind the combine, it becomes almost impossible to achieve uniform distribution. Tools such as rotary harrows, field cultivators, or disk harrows do not redistribute residue.

Where large amounts of residue are present, there are some advantages in removing a portion of the residue. Examples are small grain straw and corn stalks in high-yielding corn, especially when planting forage or fall winter grain. It may be advisable to cut straw high to achieve a better mulch cover for the following crop and then the straw may not need to be removed.



Uneven residue distribution resulted in a poor soybean stand.

STEP 5. VARIETY SELECTION AND SEEDING RATES

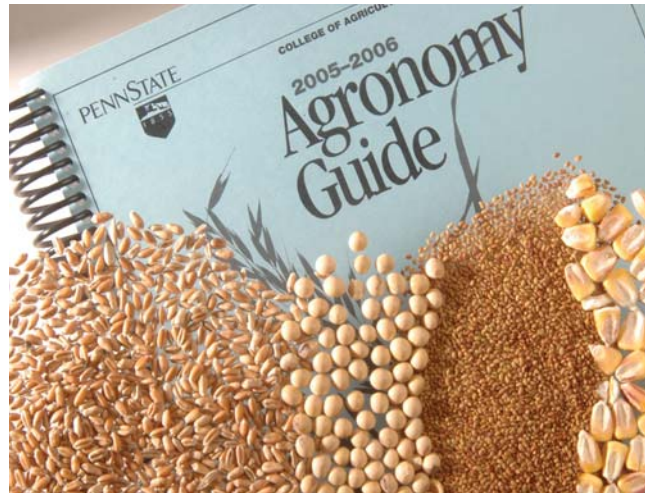
Variety selection

Selection of seed varieties, especially corn, can help make no-till planting successful. Some traits that should be considered include: (1) seed germination at cold temperatures; (2) early seedling vigor; (3) resistance to specific diseases that may survive on residue or may be common for the area.

Generally, it is a good idea to consult with a seed company's agronomist or a no-till producer in your area for help in variety selection. Also, results from the Pennsylvania Corn Growers contest will provide information on variety performance under no-till conditions. Selection of varieties for other crops is not as important but still may be worth considering.

Seeding rates

Recent technology in the seed and equipment industry, along with advanced technology to help in disease control, have affected no-till planting and seeding recommendations. In the past, standard recommendations were to increase seeding rates by as much as 20 percent. Today, some individuals increase seeding rates for soybeans and small grains. However, this may be more important owing to late planting rather than the crop being planted no-till. Generally, corn planting rates are not adjusted. There is also evidence to show that when planting small-seeded legumes and grasses, seeding rates may be decreased due to a more precise planting depth than with traditional seeders used in tilled seedbeds. When determining seeding rates, there is no better guide than to use the advice of experienced no-tillers.



Nearly all agronomic crops can be seeded using no-till equipment. Planting depth must be appropriately adjusted for each type of seed being planted.



Uniform plant population in no-till is important.



No-till corn in fall-killed sod.



No-till corn after rye cover crop and liquid manure applications.

STEP 6. INTEGRATED PEST AND DISEASE MANAGEMENT PLAN

Around the same time that you select varieties for no-till, you should also consider the weed, insect, and disease management program. If you do not have the time or experience to address the scouting aspects of pest management, you should consider hiring a certified crop advisor. The following section discusses the aspects of managing weeds, insects, and disease control in no-till.

Weed control

Weed control in no-till systems is different from that in tillage systems. Controlling weeds in no-till requires a systems approach. Crop rotation, cover crops, variety selection, and cultural practices such as optimizing soil fertility should be combined with the selection and proper application of herbicides. Scouting to identify weeds present is important for determining a proper integrated weed control plan. When starting to no-till, select fields that have low weed pressure. From then on, strive to eradicate weeds before they set seed.

WEED SHIFTS

Some weeds are more adapted to no-till than others. Large-seeded annual weeds such as velvetleaf and burcucumber become less prevalent in no-till because their seeds need to be mixed with soil for germination. Small-seeded annuals, however, can be as prevalent or more in no-till as in conventional tillage because the seeds germinate below residue mulch. Over time, however, these pressures should diminish as the seed bank is depleted if weeds are not allowed to set seed. Controlling weeds in field borders also becomes important to prevent these weeds from setting seed.

Creeping perennials that multiply through underground rootstocks, rhizomes, or tubers are adapted to no-till as well as conventional tillage systems. Simple perennials with one large taproot, however, are more common in no-till because their taproot is not broken as it is in tilled soil. Woody perennials can also become more prevalent in no-till. Despite the loss of tillage as a weed control tool in no-till, it is possible to maintain excellent weed control without the use of large quantities of herbicides if basic ecological principles are respected.

CULTURAL CONTROL

Crops compete with weeds for space, water, nutrients, and light. Whatever you can do to provide the crop with a competitive edge over weeds will therefore help in weed control. Optimize soil fertility and pH based on a soil fertility test. Use starter fertilizer to give your crop a quick start. Respect soil temperature in no-till. It may be better to delay planting no-till corn a few days compared to planting in a tilled seedbed to allow quick crop establishment. Narrow row spacing

and high plant populations will give the crop a competitive advantage over weeds. Row cleaners and zone- and strip-till will raise soil temperatures and allow the crop to establish faster. Remember, however, that certain annual weeds can become a greater problem in the tilled strips of soil.

Crop rotation is very important for weed control. Crop diversity does not allow any weed to become dominant because its life cycle is being disrupted continuously. It is best to rotate crops with different periods of growth (winter and summer crops). This will make it more difficult for weeds adapted to one crop type to get established. A good example is rotating a winter grain such as wheat with summer crops such as corn or soybeans. Rotating perennial forages with annual crops is also beneficial for weed control because of different harvest methods and timing. Rotating row crops with alfalfa or grass that is cut frequently is very effective for controlling certain woody species that might otherwise get established in no-till. The benefits of using cover crops for weed control are discussed above.

HERBICIDES

Despite the importance of cultural practices, it is not (yet) possible to grow no-till row crops without herbicides for weed control. But cultural practices can greatly reduce the need for herbicides and increase their effectiveness. Crop rotation allows for the use of herbicides that target different weeds. For example, there are more herbicide options for controlling grassy weeds in broadleaf crops, whereas broadleaf weeds are better controlled in grass crops such as corn or small grain crops.

An important benefit of crop rotation is that it allows you to avoid herbicide resistance in weed populations. This is more important to the no-tiller than to the tiller because the former cannot afford to lose the use of herbicides as a weed control tool. Continuous use of the same herbicide-resistant crops (e.g., glyphosate-resistant corn and soybeans) is an ideal scenario for increased herbicide resistance in weeds.

Burndown, residual, and postemergence herbicides are used to control weeds. Burndown herbicides are either systemic or work by contact. Systemic herbicides are translocated in the plant. Examples of systemic burndown herbicides are glyphosate (Roundup or Touchdown), 2,4-D, and dicamba (Banvel). Contact herbicides such as paraquat (Gramoxone Extra) are not mobile and kill only the vegetation that is in contact with the herbicide. Systemic burndown herbicides are suitable for killing large weeds and cover crops, whereas contact herbicides are well suited for killing smaller weeds and young cover crops. A burndown herbicide should kill essentially all the weeds present at that moment because survivors are more difficult to control later on.

Residual herbicides include early preplant, preplant and preemergent. Examples are atrazine, Dual, and Lasso. These herbicides are used to control the emergence of annual weeds for at least four weeks after application. They need to pass through the soil to the plant root and need rainfall to be mobilized and taken up by the weeds. Early preplant herbicides can generally be applied 10-15 days prior to planting. This way a farmer can avoid using a burndown herbicide, but a 10-25 percent increase in application rate may be needed to provide sufficient residual activity of the herbicide.

When using preemergent herbicides such as pendimethalin (Prowl), dicamba (Banvel, Clarity, Marksman), or 2,4-D, complete closure of the seed furrow is important or the crop will be damaged by the herbicides. Rates of soil-applied herbicides will generally increase with no-till because of higher surface crop residue and because surface organic matter content increases over time in no-till. Maintaining a proper pH is important for maintaining atrazine effectiveness. At low pH atrazine is not effective.

Postemergence herbicides are foliar-applied systemic products that should generally be applied when annual weeds are small. They will suppress broadleaf perennial weeds but are not likely to kill them completely. To control these perennials, use crop rotation so that they can be sprayed at their susceptible period, which is usually in July. Spot-spraying or hand removal may be the most practical way to prevent the spread of certain woody perennials.

Insect and disease management

Plowing under crop residue has often been recommended as a way to reduce insect and disease incidence. It is therefore logical to expect greater problems associated with pests and diseases in no-till where all crop residue is left at the soil surface. Fortunately, after many years of experience with no-till, many of the fears for dramatic yield losses in no-till due to these factors have proven to be unfounded.

With good management, insect and disease incidence is minimal in no-till. Some important principles in no-till are:

1. Stimulate predator and/or parasite activity
2. Use resistant or tolerant crop varieties
3. Increase diversity of crop rotations
4. Improve fertilization to provide optimum plant nutrition
5. Increase seeding rates (possibly with narrower rows)
6. Use integrated pest/disease management.

The lack of disturbance, moderated soil temperature, and higher moisture content under no-till provide a dramatically different microenvironment for soil and aboveground insects and other animals. Of course, the same is true for their natu-

ral enemies. Greatest pest problems in no-till can be expected after a sod or in a green cover crop.

In a sod, insects such as white grubs and wireworms have an abundance of food. Wireworms lay their eggs in the soil near the roots of grasses. The worms feed on the endosperm of seeds and bore into underground portions of the stems, resulting in aborted or weakened seedlings. Black cutworm moths are attracted to grassy/weedy patches in the field and crop residue in general. The black caterpillars cut off corn seedlings at the ground surface. True armyworm moths lay their eggs on the lower leaves of grasses or small grains beginning around April 10. When the green vegetation is killed, the green armyworm caterpillars move quickly to the young plants of the emerging crop, resulting in defoliation. Certain wasps parasitize and eventually kill these worms. In many cases these wasps are present in the environment, but they sometimes don't kick in quickly enough to avoid significant crop damage (especially in cold, wet springs). Corn rootworm survives on old corn stalks and is only a problem where corn follows corn. To control this pest, it is important to apply a soil-insecticide in the seed row. Note that predation of corn rootworm eggs has been found to be much higher in no-till than in conventional tillage.

Slugs survive under crop residue and move to the crop after a burndown treatment. Slug damage can be recognized by slimy traces on soil and plants. Slugs only remove the green, soft tissue of leaves, leaving a skeleton-like leaf behind. Soybeans are especially sensitive to slug damage because slugs feed on the aboveground growing point and seed lobes. Corn's growing point is below the soil surface for four to six weeks after germination and corn can therefore often outgrow slug damage.

Note that almost all these pest problems occur in the period shortly after crop germination. Whatever you can do to give the crop an early boost is therefore likely to result in fewer pest and disease problems. If crop growth is rapid, slug damage is usually limited and will not cause a yield loss. Starter fertilizer helps provide the crop with this early boost. Row cleaners, zone-till, or strip-till are other techniques to stimulate fast early growth. The importance of adequate potassium fertility for disease resistance is well known. A healthy crop planted in optimal conditions is more resistant to pests and diseases.

Crop rotation for insect and disease management is very important in no-till. Any insect pest or disease that survives on crop residue can be controlled by crop rotation. Examples are corn rootworm, soybean cyst nematode, and gray leaf spot. There is much interest in the benefits of improved soil quality for insect and disease control. A more diverse and active soil



Application of pesticide to a growing crop based on scouting recommendations.



Producers sometimes do their own scouting — Steve Groff, a producer in Lancaster County, checks corn planting depth in a hairy vetch cover crop. Steve's planter was equipped with row cleaners.

microbial community may reduce pest and disease incidence because of increased competition for substrate as well as predation of pests and diseases by other organisms. A cover crop can sometimes provide a “green bridge” that allows certain pests or diseases to survive on the growing cover crop. Proper cover crop selection is therefore important. Check with your seed dealer for the best crop varieties for your operation that provide resistance to pests and diseases that may prevail on your farm.

Three final notes on disease and pest management: (1) If possible, use a crop scout to review the past history of problems associated with weeds, insects, and diseases. Many pest and disease problems can be avoided through proper planning. (2) Check with other no-till farmers in your area to learn from their experiences. (3) Use a preventive rather than reactive approach to pest and disease control in the transitional period. As you learn more about no-till, you can start fine-tuning your IPM program.



Crop scout checking for emergence and presence of pest activity in a no-tilled field.

STEP 6. FERTILIZATION AND LIMING

After developing your integrated pest management program, consider fertilization and liming. There are differences in the approach to fertilization and liming in no-till compared to tillage. No-till contrasts most with moldboard plowing, whereas reduced tillage systems such as chisel plowing or disking, which do not completely invert the soil, are intermediates (Table 6). Keep the following in mind:

- In no-till, fertilizers and manure are applied to the surface, whereas with tillage they are incorporated and mixed into an 8- to 10-inch topsoil layer. Most nutrients and acidity are concentrated at the surface in no-till.
- Soil organic matter levels increase over the years in no-till. Because organic matter contains nutrients, this process will absorb nutrients that would otherwise be available to the crop. After many years of no-till, a higher equilibrium level of organic matter establishes. At that moment the release of nutrients by organic matter decomposition equals the nutrients required for the formation of new organic matter. Nutrient requirements are therefore likely to decrease in long-term no-till.
- The soil under no-till has a higher water content than a tilled soil. This means nutrients may be more available to plants, but it may also mean they are more likely to be lost through leaching and denitrification.
- Surface application of urea and manure causes higher nitrogen volatilization losses in comparison to immediate incorporation.
- The soil under no-till is cooler in the spring. This slows root growth and the uptake of immobile nutrients such as P and K. Placing these nutrients close to the seed becomes more important in no-till.

Nitrogen

Nitrogen is the most mobile plant nutrient. It can be lost from farmland in a solid form (lost with eroded soil as organic nitrogen), dissolved (leaching of nitrate), and as a gas (ammonia, nitrous oxides, or dinitrogen gas). Nitrogen losses due to erosion are greatly reduced in no-till. If soil loss on tilled soils is 10 tons/A, and organic matter content is 2 percent, 20 lbs/A of N is lost in erosion. These erosion losses can almost be completely eliminated by using no-till.

On the other hand, the potential for denitrification and ammonia losses are greater in no-till, especially on poorly drained soils. Particularly on those soils, splitting nitrogen applications reduces losses and increases nitrogen efficiency. Ammonia losses can be substantial if surface application of urea or manure is followed by a hot, dry period (up to 30

Table 6. Impacts of no-till and tillage on organic matter, pH, P, and K accumulation and distribution after 25 years of continuous corn.

	No-till	Chisel/disk	Moldboard plow/disk
Soil organic matter (%)			
Depth (inch)			
0-2	3.75	2.85	2.18
2-4	2.45	2.71	2.21
4-6	2.26	2.43	2.20
0-6	2.82	2.66	2.20
pH-H₂O			
0-2	6.48	6.33	6.30
2-4	6.50	6.65	6.58
4-6	6.72	6.83	6.58
0-6	6.57	6.60	6.48
Mehlich-3 P (ppm)			
0-2	108	60	34
2-4	41	52	28
4-6	24	35	30
0-6	58	49	31
Mehlich-3 K (ppm)			
0-2	129	127	107
2-4	83	88	79
4-6	66	70	82
0-6	93	95	89

Source: Duiker, S. W., and D. B. Beegle. 2005. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. *Soil and Tillage Research* (in press).

percent of the nitrogen can be lost). Applying manure or urea fertilizer on a cold day that is followed by showers can reduce ammonia volatilization losses. Other techniques that reduce ammonia volatilization losses are surface banding or injection of nitrogen or manure.

In the transition process, extra nitrogen may be needed if organic matter contents are increasing. For every 0.1 percent increase in topsoil organic matter content, approximately 90 lbs of N is needed. In one trial in Europe, 80 lbs/A more N was needed to achieve equal oat yields in no-till as with conventional tillage in the first four years after transition. After eight years, however, no extra nitrogen was needed to produce the same small grain yields (in this case, wheat) in no-till as with tillage. Leaching losses of nitrate were once thought to be higher in no-till compared with tillage due to increased leaching and macropore flow. However, recent research in Pennsylvania showed no higher nitrate leaching in no-till compared with tillage (Table 7).

In summary, higher nitrogen applications may be justified in no-till to compensate for organic matter buildup in the first year during the transition from conventional tillage to no-till. Greater losses may occur from denitrification on poorly drained soils and from ammonia loss if urea or manure are surface applied. The additional cost of nitrogen to build organic matter can be considered as a long-term investment like putting money in the bank. On well-drained soils, denitrification losses are not expected to be greater in no-till compared to tillage. On those soils, nitrogen requirements in long-term no-till are greater only if the yield potential of no-till exceeds that of conventional tillage.

With higher nitrogen costs, it becomes more attractive to “grow your own nitrogen” in a leguminous cover crop. It is not necessary to plow down green manure to obtain the maximum nitrogen benefits from the leguminous cover crop. The timing of the nitrogen release from the decomposing residue will, however, be dramatically different, and this can deceive the observant producer into thinking otherwise.

The rapid decomposition of incorporated leguminous crop residue results in a massive release of nitrogen early in the season. This gives the succeeding crop a tremendous boost, giving it a dark green, vigorous look early in the season. Once most of the crop residue is decomposed, however, the nitrogen release also decreases dramatically. This compares with the situation in no-till, where the decomposition of the leguminous crop residue results in gradual release of nitrogen. The timing of nitrogen release may be better in no-till because the highest demand for nitrogen is not early in the growing season but when the crop is tasseling or heading out.

Phosphorus

Phosphorus is the most immobile plant nutrient. Most soil phosphorus is not soluble because phosphorus attaches strongly to soil. Soluble phosphorus losses in surface runoff may increase in no-till; however, because no-till reduces

erosion, total phosphorus losses are greatly reduced. Soluble phosphorus losses can increase in no-till where large amounts of manure are applied to the soil surface year after year. Sound nutrient management and rotating corn with unmanured alfalfa can minimize this problem.

Phosphorus uptake by the crop is affected by soil temperature, moisture content, and banding. Soil temperature under no-till is usually lower than in tilled soil. Root growth is therefore also slower and can limit phosphorus uptake. This can cause phosphorus deficiencies to show up early in the season. To increase early-season phosphorus availability it is advisable to apply a starter fertilizer containing phosphorus in no-till. On high-testing soils, a nitrogen-only starter has been shown to be as effective as a complete starter. The moisture content of the mulched no-till soil is higher than with tillage. This higher moisture content will increase phosphorus diffusion to the root and therefore uptake. Surface application of phosphorus in no-till tends to increase its availability because less of it is fixed by soil (Table 6). This phenomenon is called “horizontal banding.” This contrasts with “vertical banding,” where phosphorus is applied in narrow strips. Research has shown there is no benefit to vertical banding in no-till to avoid P-fixation in no-till. In summary, phosphorus availability in no-till tends to improve compared to tillage systems, and losses are likely to be much reduced. Phosphorus can be broadcast on the surface except for a small dose of starter fertilizer-P injected near the seed to promote early growth.

Potassium

Potassium is a positively charged ion that is held on the exchange complex of soil. It is not very mobile. It moves somewhat with percolating water, but not very far. The result is that in no-till most potassium will be concentrated near the soil surface. In a study in Centre County, the K distribution in chisel-plowed and no-till soils were similar (Table 6). As far as potassium uptake, it does not seem to make any difference whether the potassium is concentrated at the surface or

Table 7. Mean nitrate-N leaching losses under four years of continuous corn for tilled and no-till treatments measured with wick lysimeters on a Hagerstown silt loam in Centre County.

N rate (lbs/A)	Chisel/disk	No-till	Significant difference
	Nitrate-N leaching loss (lbs/A)		
0	10	21	No
90	40	44	No
180	125	108	Yes

Source: Zhu, Y., R. H. Fox, and J. D. Toth. 2003. Tillage effects on nitrate leaching measured by pan and wick lysimeters. *Soil Science Society of America Journal* 67:1517-1523.

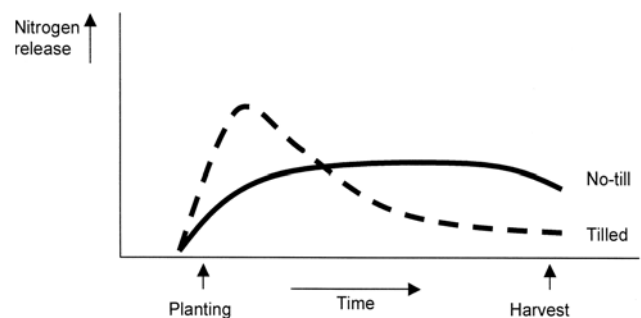


Figure 6. Nitrogen release following tilling in of a green manure will be more rapid than in no-till, but the total amount of nitrogen released will not differ.



Since pH near the soil surface can change frequently, the Cornell pH test kit can help producers monitor soil pH between complete soil sampling intervals.



A simple soil thermometer is a good tool to help producers decide when corn planting should be started; this is especially true when using no-till planting.

distributed throughout the plow layer. The only exception is during a wet, cold spring. Because potassium is relatively immobile (much like phosphorus), roots have to grow towards it to get it. In cold springs root growth is slow, which may limit potassium uptake. It is not a very common problem in Pennsylvania. Some research has shown a greater response to potassium in starter in no-till than in conventional tillage.

Liming

The major cause of the increasing soil acidity in agriculture is the application of ammonium or urea fertilizer and manure. Phosphorus fertilizer also causes some acidification, but because nitrogen needs are typically much larger, phosphorus is not a major cause of acidification.

The most acidifying fertilizer is ammonium sulfate, followed by urea and manure. Nitrate fertilizer does not acidify the soil. In no-till, all fertilizer is applied at the surface. Therefore, the acidity also concentrates at the surface. In a tillage situation, the acidity is diluted in the whole plow layer and does not increase as much near the surface. The surface pH can decrease dramatically in no-till if lime is not applied regularly. Surface acidity can cause some problems in no-till. Aluminum and manganese can become available in toxic proportions. Essential plant nutrients can become unavailable. Most fine roots of no-till crops are concentrated in the surface two inches of the soil where they take up most of their nutrients. It is therefore important to maintain an optimum pH in the surface of the no-till soil. A balanced pH in the surface soil is also important to guarantee the activity of triazine herbicides.

The high acidity at the surface of no-till soils can sometimes be missed because soil samples are taken to a six-inch depth. To check if the acidity is high, take samples from the top two inches of soil, mix them in a bucket, take a representative sample, and test pH with a cheap field kit. If the pH of this sample is lower than 6.2 but the soil test results to a depth of 6 inches do not call for lime application, apply one ton of calcium carbonate equivalent per acre.

The total amount of lime required in no-till is not greater than in conventional tillage. In a trial where corn was grown continuously for 25 years, subject to the same lime program, the surface pH was not reduced in no-till compared with tilled soil (Table 6). It is more important, however, to regularly apply lime in no-till than with tillage. If large amounts of lime are applied infrequently, huge swings of surface pH will result. This will cause pH to be quite high immediately after lime application and to be low just before the next application. It is important to avoid these swings in pH by applying lime frequently in no-till (the total amount of lime applied is not different in no-till compared to tilled systems). The other option is to use fertilizers that do not acidify the soil. Some seasoned no-till farmers have switched completely to nitrate-N fertilizers to minimize surface acidification. At low pH values, especially at 5.5 and below, tillage should be considered to incorporate lime and bring the soil profile to the desired level before starting a no-till system.

Using Manure in the Transition to No-Till

A commonly asked question is, “How can I use no-till systems and properly manage my manure?” For many years, manure management for many producers included the use of tillage at least during the years manure was applied. In no-till systems producers must consider the impacts of odors, potential loss of nitrogen, and dealing with compaction associated with heavy manure-spreading equipment. Phosphorus also becomes a consideration under current nutrient-management regulations. But before we move on, many producers who successfully use manure in continuous no-till systems have observed that manure helps the transition to no-till as well as improves soil quality in long-term no-till systems.

Odor considerations become a reality for some producers, depending on the type of manure being used and proximity to neighbors who find agricultural odors offensive. Some considerations relevant to managing odors involve neighbor relations. Many producers work with their neighbors and are considerate as to timing of manure applications. Time of the year, week, and even day become considerations. Temperatures and wind directions are also important. As the temperature increases, odors become more offensive and people tend to have windows open and are out of doors more frequently. Being directly downwind from fields with surface-applied manure can also be unpleasant. Spreading just prior to moderate rainfall helps to reduce odors as well as conserve nitrogen (½ inch of rain is considered comparable to physical incorporation). Manure additives are currently being developed and evaluated in their ability to reduce odors and nitrogen losses. For producers who must do something to physically reduce odors, equipment is available that has minimal impacts on soil disturbance while helping to reduce odors. This equipment includes shallow disk manure injectors and machinery that minimally disturbs the soil surface while helping to increase infiltration and/or soil mixing with manure near the soil surface.

The loss of nitrogen is frequently cited as the reason for using tillage with manure applications. As is shown in the *Penn State Agronomy Guide*, there is a greater potential for ammonia volatilization when manure or fertilizers containing urea are applied to the surface instead of incorporated. The ammonia is lost to the atmosphere, representing a loss to the grower, whereas most of the ammonia will eventually precipitate within 50 to 100 miles from the area of application, thus presenting an environmental threat. Not all nitrogen in manure is lost if it is surface applied. The higher the ammonium analysis of the manure, the greater the potential for ammonia volatilization. It should also be noted that ammonia volatilization losses are only reduced if manure is incorporated soon after it is applied. For spring applications, current *Penn*

State Agronomy Guide estimates of the N-availability factors of dairy manure are 50 percent for immediately incorporated manure versus 20 percent for surface-applied manure. For swine manure, N-availability factors are 70 percent versus 20 percent; for poultry manure, 75 percent versus 15 percent if we compare immediate incorporation versus no incorporation in the spring. See the *Penn State Agronomy Guide* for more detailed estimates. Farmers have to evaluate whether they need to consider manure injection in no-till.

Calculations have been completed considering the cost of tillage versus the cost of nitrogen that may be lost without tillage. In many cases, the cost of tillage does not justify its use to save nitrogen, especially when you consider additional labor and loss of long-term no-till benefits. The discussion in the preceding paragraph is also applicable to nitrogen management, particularly the consideration of application prior to rainfall so nature can do the incorporation for you.



Successful use of surface application of manure in no-till.



Soil compaction management is necessary in no-till. Using flotation tires helps alleviate surface compaction.

The Phosphorus Index is a tool that has been developed to evaluate situations where the potential for phosphorus movement to a body of water is high. The positives of no-till include significant reductions in soil erosion and, in many instances, increased infiltration and reductions in runoff. The primary negative with no-till systems is the higher phosphorus concentrations near the soil surface, which may lead to increased soluble phosphorus losses. Some management considerations to help address the phosphorus issue also include the use of riparian buffers and shallow injection or increased infiltration with specialized equipment. Also, in some instances fall applications near streams could be changed to spring applications of manure in those sites.

Soil compaction can result from the application of manure by trucks and spreaders. Sometimes this compaction should be alleviated prior to starting a no-till transition by using a subsoiler that causes little surface disturbance. In some instances, using deep-rooted crops can alleviate this problem. Consideration of which to use includes evaluating the extent and depth of soil compaction. Several Penn State publications can help you learn to evaluate and manage compaction issues. Some considerations associated with manure spreading equipment relate to the use of flotation tires and additional axles to spread the weight to where it is no longer causing compaction. Also, application on wet soils has the potential to cause more serious compaction. Today, if producers use grass hay as part of their cropping system, manure may be spread on hay fields rather than on some fields that may be going to corn. The use of drag hoses is now also becoming a part of some

producers' no-till manure management system. The drag hose eliminates the use of heavy manure-hauling equipment during the application process. When storages are not close to cropland, portable bladders or tank trucks are used to feed the system.

This publication has already addressed the use of cover crops as an essential component of no-till systems, especially during the transition period. Let it be said that the use of cover crops is also an essential part of these systems when animal manure or other organics are applied as part of the system.

In summary, many producers have been very successful using manure in no-till systems. Research is needed to evaluate the use of manure injectors and other specialized equipment discussed earlier in this section. Penn State's Department of Crop and Soil Sciences, in cooperation with the USDA Agricultural Research Service, has begun a study to evaluate some of these issues.



Rotating teeth punch holes in which liquid manure quickly infiltrates.



Surface application of solid dairy manure in no-till systems—uniform distribution is essential.



Injection system for liquid manure.



Surface application of liquid manure in no-till.



Aerator with manure distribution system and drag hose.

STEP 7. EQUIPMENT

The winter is always a good time to work on equipment upgrade and maintenance. Well-maintained and adjusted planting and spraying equipment is crucial for obtaining good stands and weed control in no-till systems. Remember, it is less expensive to properly maintain planting equipment than to operate and maintain a full line of tillage equipment.

Planter and drill

A no-till corn-soybean grower does in principle only need a planter, but drills provide many options for implementing a true no-till system. Drills can help seed hay, cover crops and small grains, or to interseed crops into hay. There are also advantages to drilling no-till soybeans. Farmers can own or lease a planter or drill or may have a custom operator do the planting for them. For a beginning no-tiller, it may be beneficial to have the planting done by a custom operator who has experience with no-till planting. Farmers can learn from the operator and eventually do the planting operation by themselves.

How do no-till planters and drills differ from conventional ones?

1. They are heavier to guarantee penetration in firm soil.
2. They have the ability to cut through stalks, straw, and growing cover and allow residue to flow through the machine.
3. They can be adjusted to plant seeds at appropriate depths for the crop-soil condition, although crop residue is present at the surface. They include both down pressure and depth control settings.
4. They cover and firm soil around the seed for complete seed coverage and protection against rodent and bird



Six-row no-till planter.

damage; and to obtain good seed-to-soil contact. This is more challenging in no-till because the soil is not pulverized, but firm.

No-till planters include or may be equipped to include:

1. residue cleaners to move residue out of the row area;
2. a starter fertilizer opener or a device to place liquid starter in the row;
3. coulters to cut through crop residue and loosen a small volume of soil around the seed;
4. metering unit to obtain accurate spacing between individual seeds;
5. seed tube to drop the seed in the seed furrow;
6. double-disk openers to open a slot to the appropriate depth;
7. seed firmer to press the seed to the bottom of the seed furrow;
8. insecticide applicator to apply insecticide in a “T”-band over the seed slot; and
9. closing wheels to cover and firm soil above the seed.

Some planters have shoe chisel, or PTO-powered rotary tiller openers, but these planter configurations perform poorly in rocky soils. Planters with single offset coulters and “T”-slot openers have not been commercialized widely in Pennsylvania.

RESIDUE CLEANERS

Residue cleaners are meant to move residue out of the row area to enable easier planting and also greater warming of the



Residue cleaners with curved fingers.



Residue cleaners with straight fingers.



A seed firmer on a planter pushes the seed down into the seed slot to achieve optimum seed depth control. Pop-up fertilizer can be applied through the seed firmer.



Residue cleaners with concave disks.



Seed firmer on a drill also pushes the seed into the bottom of the seed slot.

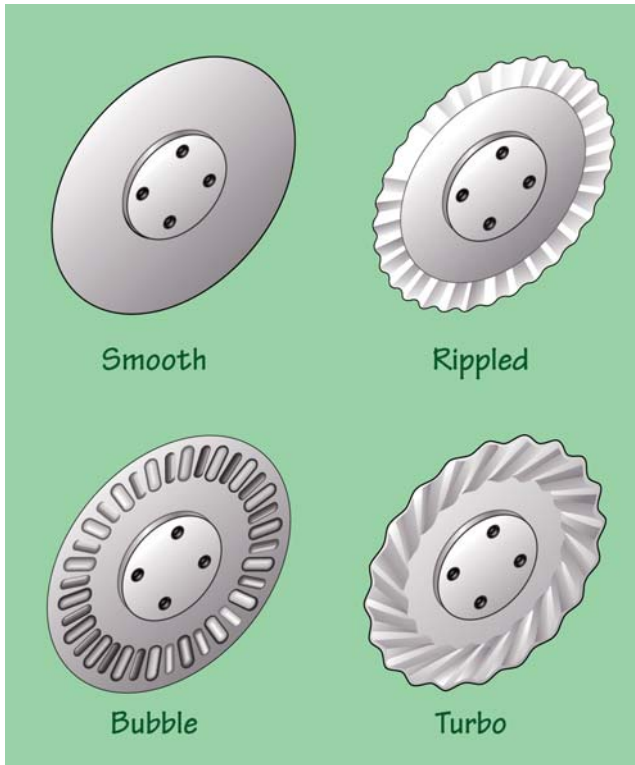
soil in the row area. Different designs are available. Residue cleaners with curved fingers have now been developed; these are less aggressive than residue cleaners with straight fingers. If the fingers intermesh they maintain better cleaning action. Residue cleaners consisting of two concave disks are also available. The latter do not cause cover crop residue to wrap around them, and they also appear to work well if packed manure has been distributed prior to planting. Residue cleaners can be unit-mounted or mounted on the toolbar. Residue cleaners mounted on the unit tend to have better depth control than those mounted on the toolbar. Some residue cleaners come as one piece with coulters. The residue cleaners are meant to move residue, not soil. The depth has to be set appropriately to avoid creating a furrow with the residue cleaners that will subsequently compromise seed depth control.

STARTER FERTILIZER OPENER

Starter fertilizer is useful in no-till, as explained earlier. Starter fertilizer openers are designed so that some fertilizer can be placed next to the seed without damaging the young seedlings. The standard method is to place fertilizer two inches next to and two inches below the seed. Liquid “pop-up” fertilizer can be placed on top of the seed. It is most conveniently applied through a little tube on the seed firmer.

COULTERS

Most no-till planters and some drills have coulters in front of the seed openers to cut through crop residue and to loosen soil. Especially in soil that has been in a long-term no-till system, you may not need to use coulters. The surface soil organic matter content will have increased and the soil tilth improved to such an extent that the seed opener disks can do an excellent job without coulters.



Smooth, rippled, bubble, and fluted turbo-coulters.

In many instances no-till coulters can perform useful functions. There are different coulters, each having specific advantages and disadvantages. The following is a general description of commonly available coulters. Equipment dealers today will help you select the appropriate one for your conditions, or you can talk to an experienced no-tiller in your area for advice on which coulters may be best for you.

1. Smooth coulters. These coulters penetrate soil most easily, because they have the smallest soil-to-surface area. They do not disturb much soil and are primarily suited to use in dry soil. These coulters do not move soil and don't help to increase soil temperatures.
2. Bubbled coulters. These coulters have a smooth edge and a bubbled section. They cut through residue well, just like the smooth coulters, but they move a little more soil. They work well in dry soil conditions, but not in wet and/or heavy soil where they can create sidewall compaction.
3. Fluted coulters. These coulters have waved edges that help move and fracture some soil. There are 13-wave and 8-wave fluted coulters. They need more down pressure than smooth and bubbled coulters and are therefore suited to moist soil that is relatively "soft." Because fluted coulters disturb and fracture some soil they help dry the soil more



A planter mounted with a bubble coulters.



A fluted coulters with angled waves to facilitate soil penetration and reduce soil disturbance.

quickly, thus increasing soil temperature and germination. Some new types of fluted coulters have waves that are angled (Turbo Coulters) to facilitate cutting residue and soil as well as reducing soil disturbance. These coulters generally are about a 20-wave coulters so they do soil fracturing.

4. Rippled coulters. These coulters are intermediate between smooth and fluted coulters.

DOUBLE DISK OPENERS AND SEED FIRMERS

Double disk openers should create a V-shaped slot, and the seed should be placed in the bottom of the trench. There are now heavier double disk openers on the market than before. Some have notches to better handle residues. Some double disk openers are offset, which helps the double disks to cut through residue and soil. For best results, use a seed firmer that gently pushes the seed to the bottom of the seed trench.



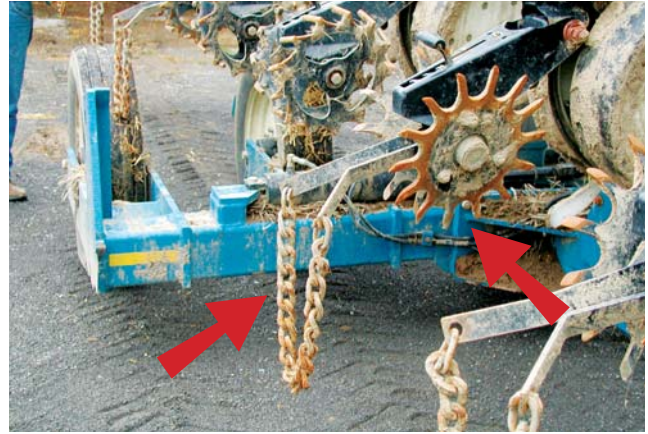
Cast-iron closing wheels.



Case-IH rubber closing wheel.



Rubber closing wheels.



Spading/closing wheels with optional drag chain.

DEPTH GAUGE WHEELS

The purpose of depth gauge wheels is to control the operating depth of the double disk openers and ultimately the planting depth. In no-till this adjustment is very critical and must be checked when planting in different types and amounts of crop residues. It is especially important to spend the extra time necessary to get the adjustment set properly when starting to plant each spring. When planting a lot of acres, as double disk openers wear, the depth will also need to be appropriately adjusted to compensate for this wear.

There are two commonly used types of depth gauge wheels (see photo on page 29). Case IH wheels are shaped to leave more loose soil next to the seed trench to reduce potential compaction in and near the seed slot and to provide additional loose soil for the closing wheels to move over the row in the closing operation. Case IH wheels are preferred when planting into soils that tend to be imperfectly drained as well

as when planting in well- drained soils when conditions are wet. Other commonly used depth gauge wheels are shaped to provide more firming action next to the double disks. Many planter manufacturers today will equip a planter with either type of depth gauge wheels.

METERING UNIT AND SEED TUBE

Different metering units are available, such as finger-pickup, vacuum, or pressure-driven systems. Metering units for no-till or conventional tillage are the same. The metering unit should be placed as close to the ground as possible. Seed tubes should therefore also be as short as possible. Smooth and straight seed tubes are advisable to guarantee minimal interference between the metering unit and the seed placement. Worn seed tubes or tubes that are not completely smooth should be replaced immediately.



Some farmers mount one fingered and one cast iron closing wheel on a planter unit.



Posi-close wheel.

INSECTICIDE APPLICATOR

The insecticide applicator for no-till is no different from that on conventional planters.

CLOSING WHEELS

Closing wheels can be made of cast iron or rubber, and are made as solid wheels or with spikes, as well as so-called “posi-close” wheels. On planters, closing wheels are meant to close the V-shaped seed slot but not compact the soil on top. On many drills, the closing wheel also controls seeding depth. Too much down pressure on drills can therefore also cause compaction on top. Closing wheels have been developed for specific purposes. In ideal soil conditions most closing wheels work fine. It is in the challenging, wet soil conditions that differences between closing wheels show up.

Cast-iron closing wheels are designed to compact soil beside and below the seed to guarantee good seed-to-soil contact



Comparison of two common types of depth gauge wheels. Case IH wheels are on the left and the other commonly used wheel is on the right.

in crumbling soils. If soil is moist, it is easy to excessively compact soil in the seed zone, which causes root penetration problems. It is important to limit down pressure on the iron closing wheels to avoid compaction, while still closing the seed slot. Rubber closing wheels pose a lower threat of compaction, but using them in soils with high clay that are moist may not provide enough down pressure to fully close the slot. This may also occur when no-tilling into spring-killed sod.

Spading or spiked closing wheels have been designed for wetter, heavier no-till soils. They are meant to crumble soil on top of the seed without causing sidewall compaction. This crumbling action tends to aid in drying and warming the soil in the row. Some spiked closing wheels come with a depth band to assure consistent operating depth. Also, as pictured above, some planters are equipped with one spiked and one solid cast or rubber closing wheel. Spiked closing wheels may not work in cover crops, especially when they are wet, because straw will wrap around them. The floating spader wheels apparently avoid cover crop wrapping as well as deep sinkage.

“Posi-close” wheels, finally, are also made for closing the seed slot in challenging no-till conditions. The pattern is meant to prevent compacting the soil excessively above the seed while still closing the slot. Drag chains can be mounted behind the seed firmers to crumble surface soil. Crumbling will only take place if the surface soil is dry.

The Case-IH slot closing system is designed differently from that on most other planter types. In this case, the seed slot is closed by two small offset disks that push soil back on top of the seed. Then a broad rubber closing wheel firms soil on top of the seed. This closing wheel system needs good soil till to work well. The closing wheel has tread to prepare a cracking pattern in crusting soils.



Many different no-till drills are available.



Winter is a good time to modify no-till equipment.



A small grain/brassica cover crop mix



A hairy vetch/oats cover crop in early spring.



A cover crop that was harvested in fall.

STEP 8. PLANTING TIME!

In the first years of transition to no-till, it is essential to plant in optimal moisture conditions. An experienced no-tiller may make adjustments in planters and modifications for planting in less-than-ideal conditions. After years of no-till surface soil tilth has improved significantly, which improves planter performance. However, as a beginner in no-till, severe problems can occur if planting is done in soil that is too wet. It is very important to know which soils on your farm are a little lighter in texture (loam and sand), so you know where conditions will be suitable first.

Planting when soils are too wet can result in sidewall compaction and incomplete seed slot closure. In heavy soil the slot may close, but if a dry spell occurs after planting, the planting slot can actually reopen, exposing the seed or seedling. It is necessary to adjust the planter for different soil moisture and texture conditions. Depth adjustments will need to be made with differences in levels and types of crop residues. Crop residue should be cleanly cut by no-till coulters and/or double disk openers. If not, hair pinning can drastically reduce plant emergence and growth by wicking valuable moisture from the seed slot, releasing acids from rotting residue next to the seed, and incomplete seed-soil contact.

Soil temperatures should be monitored before planting corn. The temperature 2 inches below the soil surface should be 50°F at 7-8 A.M., and the forecast should not call for cold weather. Most crops other than corn can be planted as early as conditions permit, which is one of the real benefits of no-till-planted small grains and forages. To reduce problems with cold soils, use an early burndown herbicide application and plant fields with low residue coverage and southern exposures first.

Another consideration in deciding where to plant first is where the soil will dry out and cause planter penetration problem when dry. Generally in our experience, the soil under soybean stubble becomes dry and hard in May and therefore should be planted first. Next are corn grain fields with last year's stubble. Generally, the preference is to plant between last year's corn rows when planting corn after corn grain. Penetration can be improved by planting closer to last year's rows if the soil does become hard. The last fields to dry out and become hard are small grain stubble from the previous year or a killed cover crop. However, if the cover crop is growing and conditions become dry, the soil can become hard more quickly under those conditions. One general rule of thumb is to plant the fields with the least cover first and advance to the most cover last. This also will help you deal with cold soils.



Final Remarks

The transition to no-till has implications for crop rotations, cover crops, field selection, residue management, crop variety selection and seeding rate, pest and disease management, fertility and liming programs, and equipment selection. Indeed, many management considerations are involved with the transition to no-till. If one does not pay attention to these basics, costly failures can result.

In this publication we emphasize the systems approach to no-till. To help in the transition to no-till, it is important to have good advice and to monitor the crops. A crop scout is therefore recommended unless someone within the farm operation commits the time and takes responsibility for doing this job. Early observations are necessary to detect needed treatments and also to monitor the effectiveness of planting operations and the fertility program.

Note that early in the season no-till planted crops, especially corn, generally do not look as good as those planted with tillage. Residue cover does not allow you to see rows and individual plants as clearly, and colder soil temperature under the residue may cause slower germination as well as P- and K-deficiency symptoms. Remember that in most instances this effect is overcome during the growing season and at harvest no-till yields are at least equal despite the poor early looks. Stands of alfalfa, small grains and soybeans may not look cosmetically as good as those planted with tillage early after planting, but again this generally does not affect yields. Consider that by using the full no-till system, you improve the efficiency, the profitability, and the environmental stewardship of your farming operation.



Cover crops offer aesthetic value as well as agronomic and environmental benefits.



Plowing in fall or winter exposes soil to the elements.



No-till soil and manure result in excellent soil structure.



Long-term (25-year) no-till soil on left and intensively tilled soil on right.



Nightcrawlers are greatly favored by no-till.



Soybean roots growing 3 feet deep in long-term no-till soil.

Sjoerd Duiker, Ph.D, is an assistant professor of soil management at the Pennsylvania State University. Sjoerd has both research and extension responsibilities in his position in the Department of Crops and Soils at Penn State University. Much of his time is devoted to the impact of no-till on soil quality management. His specialization focuses on the effects of soil management practices on soil properties and processes. He has extensive experience working in the Netherlands, Spain, Africa and the United States. Sjoerd has actively supported no-till throughout Pennsylvania and the northeast and successfully started no-till programs and field days with the Amish in Lancaster County, Pennsylvania. He has actively supported the regional no-till groups in Pennsylvania and made presentations relating to no-till systems at many producer meetings.

Joel Myers is the State Agronomist for the USDA Natural Resources Conservation Service in Pennsylvania. He has promoted no-till through his support of field days, no-till programs and other programs in Pennsylvania. He integrates the principles of no-till into numerous training sessions he conducts. His personal farm experience with complete no-till systems has enabled him to discuss the practical aspects of no-till with producers, agency personnel and others. Joel has spoken several times at the National No-Till Conference. He has been a member of the Mid Atlantic No-Till Conference for over 20 years and has supported and helped start 3 regional no-till groups in Pennsylvania. He has also been working with researchers and equipment representatives to address the issues of managing manure in no-till systems.

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