Published November 15, 2018

Transitional

What is it and how does it differ from 'true' no-till?

No-till is not really no-till until the soil achieves a physical, biological, and chemical balance typical after several years of continuous no-till. Early years of no-till research must be identified as "transitional no-till." Any interruption of continuous no-till with a tillage operation resets the soil clock, and the changes are not realized and may even be reversed. In this overview, we present the case for why no-till systems achieve the positive results on soil properties and why not disturbing the soil is necessary to restore soil functionality. Earn 1.5 CEUs in Soil & Water Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/612.

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doi:10.2134/cs2018.51.0603

Soil changes under no-till are gradual and depend on continuous use of no-till practices. Changes in soil aeration, earthworm populations, fertility, water infiltration, available water capacity, soil structure, water-stable aggregates (WSAs), soil organic matter (SOM), humus, and microbial buildup require time to develop. Hatfield et al. (2017b) demonstrated changes in soil required a stable microclimate in the upper soil profile for the biological systems to properly function and to facilitate changes in soil quality. Without soil biological activity, there is no humus (Clapperton, unpublished, 2012) and no change in the soil properties (Hatfield et al., 2017b). When transitioning to no-till, Monsanto (unpublished, 1994) noted the following:

"No-till systems do not mix residue in the soil. This means organic matter breaks down in the top several inches of soil. Studies of long-term no-till show the soil organic matter levels can increase by 100% in the surface 2 inches of the soil profile. With most soils, it will take several years (three to six) of continuous no-till before the effect is noticeable."

The accumulation of SOM on the surface impacts the soil physical, chemical, and biological properties and affects soil health and crop productivity over time. Disruption of a no-till system by any form of tillage in any of the transitional years negates all of these beneficial changes (Reicosky, 2015).

If a farm family has 1,000 acres of soybeans planted no-till after corn and 1,000 acres of corn planted after fall chisel plow and spring disking, how many acres of this 2,000-acre corn–soybean rotation are no-tilled? Most people, including the federal government agencies, would say "1,000 acres no-till." The more accurate answer is zero! Soil that is tilled every second (or third) year is not no-till. This is "rotational tillage," which is the most typical practice for Midwest farmers with a corn and soybean crop rotation. According to Ohio State University, greater than 75% of corn planted is after fall chisel plowing of the previous crop (Hoorman et al., 2009).

Shallow vertical tillage units disrupt the entire soil surface to a depth of 1 to 4 inches, leaving the soil fractured and loose with crop residue broken up and mixed with the soil. Shallow tillage is widely used with continuous corn as an aid to breaking up the corn stalks. Even if that is the only tillage pass before planting corn, it is not no-till.

In this overview, we present the case for why no-till systems achieve the positive results on soil properties and why not disturbing the soil is necessary to restore soil functionality. Soils are a critical part of the infrastructure required for the production of food, feed, and fiber and are often ignored as foundational to meeting these needs (Hatfield et al., 2017a). Hatfield (2014) showed how soil degradation threatens future productivity and is the result of soil management practices that disturb the upper soil profile.

What is no-till?

Adding crop residue year after year on the soil surface provides carbon and nitrogen "food" for soil microorganisms. Crop residue is important to kick-start the biological, chemical, and physical transformation of soil to obtain full no-till ecosystem functionality. This blanket of crop residue helps to increase soil moisture and reduce soil temperature and soil water evaporation. This crop residue is also necessary to moderate the soil microclimate and reduce the raindrop energy, directly impacting the soil surface (Hatfield and Prueger, 1996). Cooler soil temperatures are more favorable for increasing microbiological activity,

Photo courtesy of the United Soybean Board.

no-till

earthworms, and all members of the food web. Crop residue and organic matter left anchored to the soil surface are not easily lost to wind or water erosion. The microorganisms and earthworms responsible for breakdown are concentrated near the soil surface.

Crop residue on the surface accumulates as SOM and can increase SOM in the top 2 inches by 1% in seven to nine years (Hoorman et al., 2009). "SOM is the primary food source for most soil organisms" (Lucas, 1982). The quantity and quality of SOM drives nutrient cycling. A carbon-to-nitrogen (C:N) ratio of crop residues or roots between 20:1 and 30:1 is ideal for nitrogen cycling (Clapperton, unpublished, 2012). However, "for the first several years after converting to no-till, there is competition for N as soil productivity increases and more nitrogen is stored in the soil in the form of soil organic matter and humus" (Hoorman et al., 2009). Initially, soil bulk density increases, before decreasing. "It takes several years of continuous no-till to fully realize positive changes in bulk density. This may explain why after converting to a no-till system for one to two years, crop yields may be slightly lower than conventionally tilled systems when compared side by side in the same field" (Monsanto, unpublished, 1994).

However, recent observations on the changes in the aggregate dynamics of the soil surface show there are changes after one growing season, and these aggregates are fragile and easily destroyed by any form of tillage (Wacha and Hatfield, unpublished, 2018). Long-term no-till soils generally have more pore space and lower bulk densities than conventionally tilled soils. The lower bulk densities of no-till are due to old root channels and earthworm burrows filled with active or slow SOM pools locked inside WSAs created by fungus, roots, soil microorganisms, and worm excrements (Monsanto, unpublished, 1994).

What is transitional no-till?

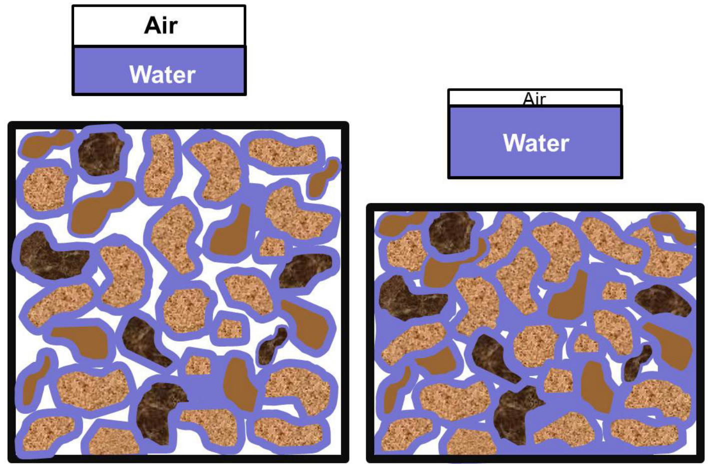
Once soil is transformed into a fully functioning no-till field, the soil health improvements measured or observed in soil no-tilled for five to nine years can be eliminated in one tillage pass. For example, a research study of continuous no-till corn after five years found that WSAs or soil aggregation increased 120% under no-till with the accumulation of SOM on the surface. Moldboard plowing destroys aggregate stability along with reduced amounts of microbial biomass carbon (Panettieri et al., 2013). Tillage can increase the loss of CO_2 released by soil respira-

Soils abused by tillage and erosion do not have a diverse soil biological community and have limited water infiltration or gas exchange rates. This photo shows differences in structure between no-till soils (left) and the powdery topsoil found in a conventional till soil (right) in South Dakota. Source: USDA-NRCS South Dakota.

tion (Reicosky and Lindstrom, 1993). Tilled soil creates better accessibility to oxygen for bacterial decomposition and microbial respiration, resulting in the release of CO_2 due to the improved aggregate structure near the surface (Reicosky and Lindstrom, 1993).

Transitional no-till represents the years from the beginning of no-till until the soil is truly transformed to have no-till characteristics. The number of years required to complete the transition can be shortened by practices such as cover cropping, adding manure or compost, utilizing diverse crop rotations, and maintaining crop residue on the soil surface. In research, the results during the transition are important and critical to understand the soil dynamics; however, the results should not be referred to as "no-till" until the soil has reached the biological, physical, and chemical status of true no-till.

It is important to understand the processes soils will go through during the transition phase. Soils abused by tillage and erosion do not have a diverse soil biological community and have limited water infiltration or gas exchange rates. The loss of SOM, resulting from decades of tillage, increases the bulk density of soil because the soil aggregates are unstable. Bulk density is a primary



Soil compaction changes pore space size, distribution, and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space decreases within a soil, the bulk density increases (higher bulk density shown on the right). Long-term no-till soils generally have more pore space and lower bulk densities than conventionally tilled soils. Illustration courtesy of Jodi DeJong-Hughes, UMN Extension.

measure of soil aeration and soil compaction, and from its definition, shows why a high bulk density has little pore space. It is defined as the ratio of oven-dried soil (mass) to its bulk volume, which includes the volume of particles to the pore space between the particles. According to Lucas and Vitosh (1978), the ideal mineral soil would have a bulk density of 1.3 g/cm^3 and 2.8% SOM. However, eroded side hills in the Midwest often have a bulk density reading of 1.6 g/cm^3 or greater where the loam topsoil is thin and SOM is depleted (Mokma, unpublished, 2008). Logsdon and Karlen (2004) observed during a conversion from conventional tillage practices to no-till on a loess soil that there was no increase in bulk density with no-till practices. Each soil will vary in the response of bulk density, but producers can manage changes in bulk density to be a non-limiting factor during the transition phase.

Tilling soil wet increases bulk density with the first pass over the field (Steinhardt et al., 1979; Voorhees, 1987). At a bulk density of 1.8 g/cm^3 (sand) or 1.5 g/cm^3 (clay), soil is dense (hard), difficult to till, and compacted. Water erosion and runoff increase with compacted soils because infiltration is limited. Also, plant roots are restricted at a bulk density of 1.8 g/cm^3 (sand) or 1.5 g/cm^3 (clay) (Arshad et al., 1996). At these bulk densities, soil compaction probes show readings above 300 psi when soil moisture is at field capacity, which is generally considered the resistance where plant roots cannot penetrate the soil. (Gugino et al., 2009). However, "Penetration resistance depends strongly on the soil water content: the dryer the soil, the greater the resistance to penetration. Penetration resistance is best determined when the soil is near field capacity" (Gugino et al., 2009). It takes several years of true no-till to show improvement in bulk density through SOM changes.

Compact soils with high bulk density have little porosity. Although deep tillage is often used to break compaction layers, deep-rooted crops like alfalfa or cover crops such as Diakon radish and cereal rye can be equally or more effective. In as little as three years, continuous no-till with cover crops that root deeply can show changes in soil bulk density (Hoorman et al., 2009), porosity, and infiltration.

Soil organic matter and long-term no-till soils

In just over 100 years, tillage has decreased soil organic matter by 60% (Lal, 2004). Soil organic matter on 29 million acres of Texas Blackland soils (Wallace, 1995) has been reduced 50% or more by tillage and erosion. Once SOM sources are depleted, N, P, and K cycles cease to operate efficiently without SOM to feed the soil microbial cycles. Soil becomes addicted to fertilizer to maintain productivity. Fertilizers are used to provide nutrients once provided by the food web, manure, or cover crops. Tillage breaks apart WSAs and exposes SOM in the slow

Poor aggregate stability associated with excessive tillage will cause decreased water infiltration, increased water runoff, and increased soil erosion. The soil aggregate sample on the left is from a conventionally tilled field. The soil aggregate on the right is from a no-till field. Source: USDA-NRCS South Dakota.

pool to bacteria. True no-till soils have more pore space and a lower bulk density due to old root channels and earthworm and fungal activity. True no-till soils are alive with mycorrhizal and saprophytic fungus activity that use the plant residues for food and produce or release organic sources of N, P, and K for plants to use (Edwards et al., 1999). Less fertilizer is needed to maintain or improve yields under true no-till (Haney, 2015).

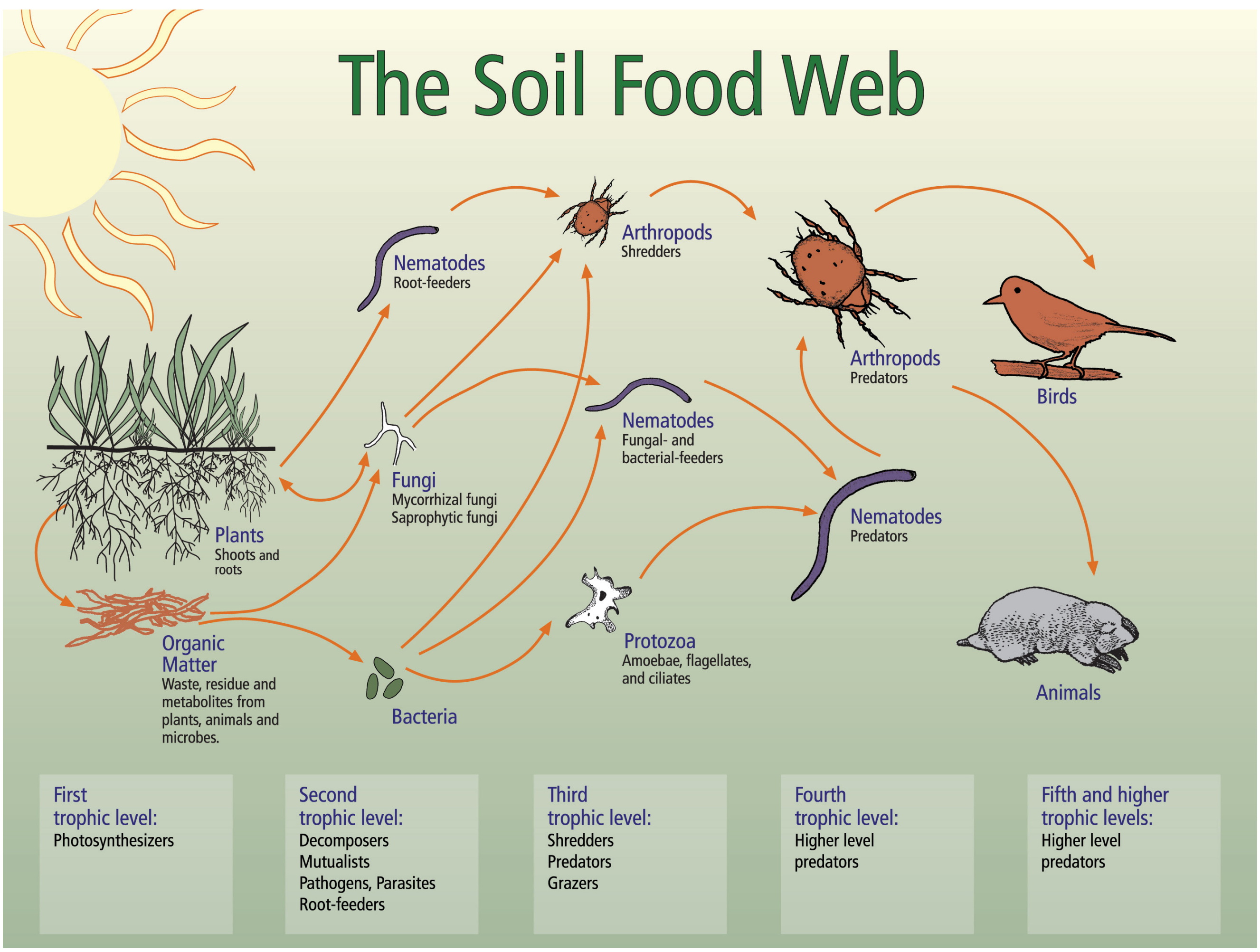
Soil organic matter is the first soil component lost by water, wind, and tillage erosion. “Soil erosion can be a major source of SOM loss” (Lucas and Vitosh, 1978). Soil organic matter is exposed from inside the WSAs by tillage or splash, sheet, rill, or wind erosion forces. After WSAs are granulated to small particles by these destructive forces, SOM easily floats away in runoff or is decomposed by bacteria that releases carbon dioxide. Lucas and Vitosh (1978) found that, “The organic content of soil materials removed by soil erosion can more than double that found in the original soil material.” However, personal communication with Dr. Lucas (1992) concluded that “correction is badly needed for (predicting) soil erosion of OM sources.” Without active sheet and rill erosion, WSAs protect active organic matter and slow SOM from destruction. Allowing organic forms of nutrients to build up over time results in increased productivity. After several years of continuous no-till, the SOM nutrients inside WSAs are a source of organic N and P, providing more than one-half the N and one-quarter the P for corn (Hoorman et al., 2009).

As SOM increases under long term no-till, soil bulk density decreases, and plant roots can utilize organic sources of nutrients deeper in the soil profile and bring them to the surface. Plant-available water from deeper in the soil profile becomes a pathway for organic nutrients. Mitchell (1980) grew continuous no-till corn grain in Delaware for eight years and followed each fall with a hairy vetch and rye cover crop. After eight years in no-till corn and hairy vetch and cereal rye cover crops, organic nutrients accumulated at the soil surface, creating nutrient stratification of N, P, K, SOM, and other nutrients. Mitchell measured the accumulation of nutrients in the top 3 to 9 inches of soil after eight or more years of no-tillage in different crop rotations (Mitchell, 1980). There was considerably more organic N, K, Ca, P, and OM after eight years of no-till corn on this coastal piedmont loamy sand soil.

Excessive soil erosion, also called soil compaction or tillage erosion, depletes SOM, the storehouse for nutrients. Low OM in soil creates an “addiction” to external fertilizer inputs to provide nutrients for plant functions because there is limited internal cycling of nutrients. There is little soil biology in the soil aggregates to retain nutrients once exposed by tillage. No glomalin, sugars, or fungal hyphae roots are there to form WSAs. The soil biological community is dominated by bacteria waiting to consume SOM (C and N) in the next tillage cycle that breaks apart residue and soil aggregates for the bacterial feast that follows.

Bacteria need a wound to enter the crop residue to break it down. Tillage that sizes and splits apart residue and roots into small pieces is the "wound" bacteria need to consume the carbon protected inside WSAs. Adding water, oxygen, and warmth (heat) fuels the aerobic bacteria fire to consume carbon, turning it into carbon dioxide (CO_2). The nitrogen found in exposed glycoprotein is used to build protein for the exoskeletons of soil microorganisms. Tillage robs the soil of C and N when it breaks apart WSAs and exposes glomalin, which is the glue that binds aggregates. Soils respond by forming hard clods, crusting, developing tillage pans, becoming compacted, and ponding after heavy rainfall events. Twenty-nine million acres of Texas Blackland soils once rich in SOM have lost more than half the original 7 to 8% SOM, which has since been broken by plowing shortgrass prairie (Wallace, 1995). Because of years of SOM decline due to intensive crop rotations needing nitrogen since the 1880s and excessive tillage that destroys WSAs that protect active organic matter and slow SOM from destruction, Texas Blackland soil's slang name today is: "Texas Waxland" due to lack of soil tilth.

Beneficial bacteria that feed on the crop residue enhance soil quality over time by: (1) becoming food for other members of the food web; (2) decomposing crop residue and roots, thus creating SOM; (3) retaining nutrients in the root zone, thus preventing N and P loss to ground and surface water; (4) increasing infiltration and



Once the food web is the primary tillage system replacing conventional or conservation tillage and soil transformation is complete, you have true no-till. This food web diagram shows a series of conversions (represented by arrows) of energy and nutrients as one organism eats another. Source: USDA-NRCS.

WSAs and reducing runoff; (5) competing with disease-causing organisms; and (6) degrading pollutants as water is filtered by soils (Edwards et al., 1999). Ecosystem functionality returns with the adoption of long-term no-till.

In Delaware research, after eight years of continuous no-till corn with a rye and hairy vetch cover crop each fall, Mitchell (1980) observed that the soil samples from the no-till fields contained 30% more potassium than soil from the tilled field. He found in the no-till fields that SOM, plant-available nitrogen, and potassium increased significantly in the top 3 inches of this loamy sand soil. Corn yields responded positively even in dry years. Mitchell (1980) describes the rye and hairy vetch cover crops as the "potassium pump" responsible for a 60% increase of potassium in the root zone of eight years of continuous no-till corn with rye/vetch cover crops.

Soil organic matter can accumulate faster with active carbon sources like hairy vetch and rye cover crops in long-term no-till crop rotations and improve soil ecosystem functionality (Hoorman et al., 2009). The nutrient enrichment of soil by the fungi food web is responsible for the accumulation of active carbon, organic phosphorus, and nitrogen in the top 10 cm of soil under continuous no-till. Unlike bacteria, fungi can use N from the soil, allowing them to decompose hard-to-digest residue, which is often low in nitrogen. Long-term no-till benefits from surface residue and old roots because they provide a source of carbon for saprophytic fungi (decomposers) that recycle carbon and nutrients chemically locked up in the residue. These decomposers convert dead roots and residues into fungal biomass, carbon dioxide, organic acids, and microorganism exudates.

Soil water availability and no-till

Long-term no-till is "crop insurance" against drought. The old root channels and earthworm burrows increase SOM levels slowly over time and store more plant-available water in the soil profile (Edwards et al., 1989). However, transitional no-till years may still require protection of farm income from catastrophic yield loss by buying crop insurance because soils are not providing the same benefits to plants as true no-till.

Crop rotations, no-till, and adjustment management systems

Crop rotations provide residue to make transitional no-till more successful. Rotations such as corn on corn, corn into sod, and wheat on wheat are difficult to introduce into no-till. It is much easier to no-till after soybeans, dry beans or after straw was removed after wheat harvest and planted to cover crops (Hoorman et al., 2009).

Another complaint in transitional no-till is that the residue on the surface makes it harder to obtain a uniform stand with the desired plant population. Poor stands have often been attributed to poor seed–soil contact due to poor residue management in no-till. A key component of long-term no-till is to ensure adequate residue is available throughout the year to keep the soil biology active. Several crop residue management alternatives are practiced by long term no-till farmers to handle "all that residue" from high-yielding corn or wheat stubble. Small-grain growers bale the straw. Some farms chop and harvest wheat straw for cattle feed or spread the residue windrows by mowing. Some farms spray corn residue with Accomplish, citric acid, 28% UAN, or liquid manure to speed residue decomposition. On successful long-term no-till farms, residue management begins at harvest by evenly spreading the chaff with a chaff spreader and leaving the stubble as high as possible. Some innovative farmers leave tall standing corn stalks at harvest to help warm the soil the following spring.

However, tall standing corn stalks can dislodge drive chains on planters. In order to prevent chains from being dislodged by standing corn stalks, shields are added to the parallel link arms on the planter, or a "leaning" bar is added ahead of the planter to lean the residue in the same direction as planting (Jasa, 2013). Another strategy to obtain a good stand of corn after corn stalks is to plant several inches off the old row or plant down the center of the old corn rows. Planting off the row helps prevent seed bounce on the planter that can occur when trying to plant on the old row (Jasa, 2013). Running three coulters per row at planting and using row cleaners on each planting unit also improves seed–soil contact. Slowing down planting speed to 3–4 mph is another strategy for getting a good stand of corn or soybeans after corn. Good stands of no-till corn or soybeans after corn can be achieved by implementing a combination of these residue management methods. It is necessary to adapt planting equipment to handle the residue accumulation in the early years of true no-till until the soil biological community increases in sufficient number to recycle the crop residues into the soil. However, producer attitude toward residue management must change to handle residue buildup.

Transitional no-till

Short-term three-year research studies that convert a conventionally tilled field, start no-tilling, and call this a no-till system often have lower yields and bad comparison data. If the soil was previously compacted by heavy equipment, the soil has not yet made the transition to "true" no-till. It often takes seven to nine years to correct the "tillage effect" and give the soil time to heal the natural biological communities. Therefore, it is our opinion that all past or future short-term research trials (three years or less) should use the term *transitional no-till* to describe the soil's health condition when comparing other tillage systems to no-till. These soils in transition are not yet providing the same ecosystem services observed under long-term no-till.

Observations by long-term no-till farmers note the conflicting information in existing continuous no-till research. To seek the truth from continuous no-till research data, Duiker et al. (2014) suggest the following:

1. Were yield data and other relevant results taken from land that has been no-tilled for at least three years?
2. Were management techniques to improve soil health a part of this system?
3. Was planting equipment adjusted, maintained, and equipped with attachments needed to plant under continuous no-till conditions?
4. Were the timing of planting and management appropriate for continuous no-till systems?

It is our opinion that short-term university no-till research studies do not pass (at least) one of the four questions listed above (Duiker et al., 2014). Therefore, long-term no-till farmers need to do their own on-farm comparison to seek the truth about which management methods improve profits with long-term no-till.

The goal of true long-term no-till and cover crop organic system research is to restore soil microbial communities and provide plants with the soil biology, physical characteristics, and chemistry to create productive soils. We propose to call the return of soil ecosystem services and functions *true no-till*.

Until a soil has healed from abusive tillage and erosion in the early years of continuous no-till, the soil is still in transition and does not provide the same ecosystem services as long-term no-till. However, after several years of continuous no-till, the soil biology is restored to a more natural community dominated by fungus that helps provide increased organic N, P, and K nutrients and other ecosystem services like carbon sequestration, improved infiltration, increased available water capacity due to WSAs, etc. Once the food web is the primary tillage system replacing conventional or conservation tillage and soil transformation is complete, we have *true no-till*. Any past, present, or future no-till research comparisons prior to Year 7 should be called *transitional no-till systems* parallel to *transitional organic systems*.

*The References are omitted here due to space constraints but can be viewed online at dx.doi.org/*doi:10.2134/cs2018.51.0603. *See CEU quiz on opposite page.*