FEATURE

John R. Teasdale

Strategies for soil conservation in no-tillage and organic farming systems

Above: Corn growing in a no-tillage system plot as part of the long-term Sustainable Agriculture Demonstration Project at Beltsville, Maryland. The high residue cover is typical of long-term no-tillage crop production in the mid-Atlantic area. Photo by Dave Clark.

No-tillage cropping systems are known to provide many benefits to soils that can enhance production of grain crops. Many of the improvements to soils that result from no-tillage production such as increases in soil aggregation, water-holding capacity, nutrient cycling, and biological activity are related to increases in soil organic matter. No-tillage systems are known to increase soil organic matter because of the absence of destructive tillage operations, the minimization of soil erosion losses, and the return of crop residue to the soil. Organic matter can be further enhanced by the addition of cover crops, perennial crops, and organic amendments into no-tillage rotations.

Organic farmers share many of the same goals for building soil organic matter, fertility, and the capacity for supporting soil biological activity and productivity as no-tillage farmers. In organic farming this is achieved through integrated systems that maintain living vegetation cover, return vegetative residue back to soils, and add organic amendments from external sources as needed. The dilemma for organic farmers is that these approaches for increasing soil organic matter also require tillage. Specifically, tillage is required (1) to eliminate perennial legumes or winter annual cover crops before planting annual crops, (2) to incorporate manure to avoid nitrogen (N) runoff and volatilization losses, and (3) to prepare a seedbed and control weeds. Since an increase in tillage intensity and frequency has been shown to decrease soil matter, gains in organic matter by the addition of organic materials into the system may be offset by decreases in organic matter from tillage. Some authors have speculated that conventional no-tillage agriculture may provide superior soil improvement and potential environmental benefits compared with those of organic farming because of the tillage requirements of organic farming (Trewavas 2004). There is a need for long-term research to assess the relative merits of conventional no-tillage agriculture compared with those of organic farming (Macilwain 2004).

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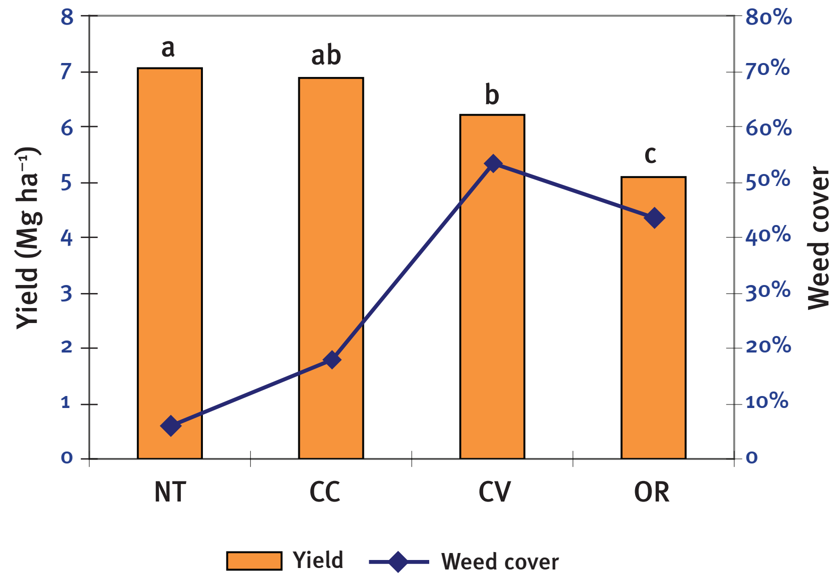
John R. Teasdale is a plant physiologist at the Sustainable Agricultural Systems Laboratory, USDA Agricultural Research Service, Beltsville, Maryland.

RESEARCH COMPARISON OF NO-TILLAGE AND ORGANIC SYSTEMS

In response to this need, a long-term experiment, the Sustainable Agriculture Demonstration Project (SADP), was initiated at Beltsville, Maryland, to compare selected no-tillage grain cropping systems and a reduced-tillage organic system on a sloping, droughty site typical of the mid-Atlantic area (Teasdale et al. 2007). A two-year corn (*Zea mays* L.)–wheat (*Triticum aestivum* L.)/soybean (*Glycine max* [L.] Merr.) rotation was used with variations adapted to each system. Four systems were compared: (1) a standard no-tillage system (NT) with recommended herbicide and nitrogen inputs, (2) a cover crop-based no-tillage system (CC) including hairy vetch (*Vicia villosa* Roth) before corn with reduced herbicide and nitrogen inputs, (3) a no-tillage crownvetch (*Coronilla varia* L.) living mulch system (CV) with recommended herbicide and nitrogen inputs, and (4) a chisel-plow based organic system (OR) with cover crops and manure for nutrients and post-plant cultivation for weed control. The standard for comparison was NT, which was typical of that used in the mid-Atlantic area. The two additional no-tillage systems, CC and CV, were compared to this standard for their potential to improve soil organic matter, reduce external inputs, and enhance environmental protection on erodible soils. Finally, OR was designed to reduce tillage to the minimum necessary for incorporation of manure and for weed control. All systems were designed to be as sustainable as possible, specifically that (1) at least one grain crop would be harvested in every year, (2) crops would be rotated, (3) soil would be covered with vegetation or residue during as much of the rotation as possible, and (4) tillage would be minimized to the extent possible within each system. Since herbicides were permissible in the first three systems, these were maintained completely without tillage. The organic system reduced tillage to chisel plowing/disking and high residue cultivation for weed control and otherwise kept the soil covered

Figure 1

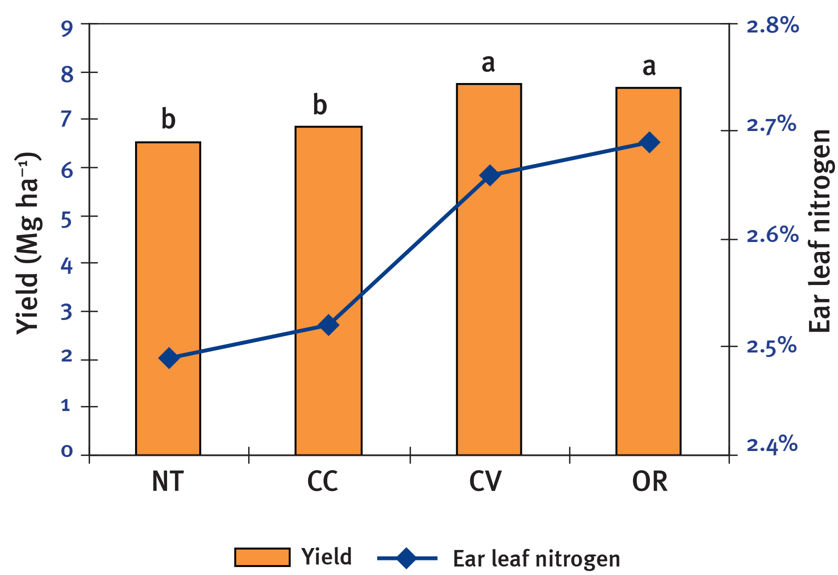
Average corn yield and percentage of area covered by weed vegetation at weed maturity in the no-tillage (NT), cover crop (CC), crownvetch (CV), and organic (OR) systems (1994 to 2002).



Notes: Bars with the same letters are not significantly different ($p < 0.05$). All weed cover symbols are significantly different from each other. Corn grain conversion: 6.27 Mg ha^{-1} = 100 bushels ac^{-1}.

Figure 2

Corn grain yield and ear leaf nitrogen at silking averaged over the years of the uniformity trial (2003 to 2005).



Notes: No-tillage corn was grown over all plots that had a history of the no-tillage (NT), cover crop (CC), crownvetch (CV), and organic (OR) systems from 1994 to 2002. Yield bars with the same letter are not significantly different ($p < 0.05$). Differences between ear leaf nitrogen symbols follow the same letter designations as yield bars. Corn grain conversion: 6.27 Mg ha^{-1} = 100 bushels ac^{-1}.

with crops, cover crops, and/or residue.

These plots were not designed to permit direct measurement of erosion. However, a simulation study was conducted using the Environmental Policy Integrated Climate model (USDA ARS, Temple, Texas), which uses the Revised Universal Soil Loss Equation to simulate erosion for these systems over a 60-year period (Watkins et al. 2002). This study predicted average annual soil erosion losses of 3.45, 3.10, and 3.69 Mg ha^{-1} (1.54, 1.38, and 1.65 tn ac^{-1}) for the NT, CC, and OR systems, respectively. The CV system could not be simulated because the model version used did not permit growing two species simultaneously (newer versions can do this); however, the CV system would be expected to reduce erosion losses compared to the other systems because it included a perennial living mulch superimposed on the NT system. This simulation suggested that there were not significant differences in erosion potential and that all systems were considered likely to maintain soil erosion losses within reasonable soil loss tolerance levels.

During the nine years of the systems' comparison, 1994 to 2002, corn yields were similar in NT and CC, but were 12% lower in CV and 28% lower in OR than in NT (figure 1). Competition from the perennial crownvetch living mulch and inability to adequately control weeds in the minimum tillage organic system accounted for yield losses. Weed control was good in NT and CC except for selected years when late season grasses escaped the CC postemergence-only herbicide program. Use of a Roundup-ready weed management program that was not available for corn during most of the experimental period would have improved the efficacy of this system. Weeds were controlled satisfactorily in CV but the crownvetch living mulch averaged more than 50% ground cover and acted as a weed, competing with corn for available resources. Weed populations built up at the soil surface because of the minimization of tillage in OR and led to increasingly poor weed control as the experiment progressed.

There were no statistical differences in soil carbon (C) or N concentrations among systems at the beginning of the experiment. After nine years, the OR system had higher soil C and N concentrations at all depths to 30 cm (12 in) than all other systems. The CC system had higher soil C and N concentrations than the NT system to 15 cm (6 in), but the CV and NT systems had similar soil C at all depths. These soil C levels reflect the quantity of organic biomass added to soil in these systems; OR returned not only crop residue and cover crop biomass but also imported high levels of manure biomass.

A uniformity trial was conducted from 2003 to 2005 with corn grown on all plots according to the standard no-tillage system with recommended fertilizer and herbicide inputs. Yield of corn grown on plots with a nine-year history of OR and CV were 18% and 19% higher, respectively, than those with a history of NT (figure 2). There were no differences between corn yield of plots with a history of NT and CC. Corn ear leaf N at silking (figure 2) and pre-sidedress soil nitrate (data not shown) were higher in the OR and CV than in the NT and CC systems during this uniformity trail. This suggests greater N availability accounted for higher corn yields in plots with a history of OR and CV than those with a history of NT and CC.

BENEFITS AND LIABILITIES OF NO-TILLAGE AND ORGANIC SYSTEMS

Results of this research suggest that organic farming systems can provide greater long-term soil improvement than conventional no-tillage systems, despite the use of tillage in organic systems. Other research has also shown that organic systems can increase soil organic matter compared with conventional systems. Manure- and legume-based organic farming systems from nine long-term experiments across the United States were shown to increase soil organic C and total N compared with conventional systems (Marriott and Wander 2006). Crop yields and/or soil organic C were increased by organic versus conventional cropping systems in the east (Pimentel et al. 2005), Midwest (Delate and Cambardella 2004), and west (Clark et al. 1998). These experiments involved primarily tillage-based systems whereas our SADP research showed similar results under no- or minimum-tillage conditions.

This research also demonstrates, however, that the soil-building benefits of organic farming may not be realized because of difficulty controlling weeds in organic systems, particularly reduced-tillage organic systems. Additional research is needed to develop reliable weed management for reduced-tillage organic farming. Advances in equipment design (Rodale Institute 2007) have led to improved control of annual weeds by rolling cover crops to form a dense, tight mat of residue in no-tillage organic systems. In addition, research (Teasdale et al. 2004) has shown that more diversified organic systems with perennial hay crops in the rotation maintain a lower weed seedbank and lower weed abundance than those following simpler grain crop rotations such as those used in the SADP research. Using rotations with perennial hay crops would both benefit organic systems by reducing weed populations but also eliminate tillage during a significant portion of the rotation. Therefore, with inclusion of a perennial crop, the soil building benefits of no-tillage could be obtained during the perennial phase of the rotation and the negative consequences of tillage during the grain crop phase would be minimized.

Alternately, results of this systems experiment suggest that conventional no-tillage systems could benefit from additional organic inputs and/or perennial rotational crops to improve the sustainability of these systems. This research shows that finding opportunities for adding cover crops, perennial crops, or organic amendments to no-tillage systems could increase soil C, which, in turn, would be expected to create associated improvements in soil physical, chemical, and biological properties. This research also shows that these soil improvements could lead to higher long-term yield potential of no-tillage systems.

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