Tillage Effects on Soil Carbon Accumulation

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Summary:

Data from existing long-term field experiments provides the best source of knowledge about tillage and other production management effects on soil carbon content. The preponderance of this data shows that that adoption of no-tillage increases soil C, relative to conventional tillage, in most U.S. cropland soils.

Background:

Numerous studies of replicated, long-term field experiments comparing conventional tillage (e.g. moldboard plow, chisel, disk) and no-tillage have demonstrated that most soils, following conversion to no-tillage, show an increase in soil carbon (C) content relative to tilled soils, when the measurements are integrated over the full depth of soil affected by tillage (typically the top 20-30 cm) (see reviews by Paustian et al. 1997, West and Post 2002, Ogle et al. 2005). In general, positive soil C responses are obtained first after several years of no-till management (Six et al. 2004) and after 20-30 years, the relative rates of C accumulation tend to decline as soil C levels approach a new equilibrium level under no-till conditions (West and Post 2002). Specific mechanisms by which the physical disturbance from tillage increases soil C loss (and conversely, that reduce soil C loss under no-till) have been proposed and supported by field and experimental evidence (e.g. Six et al. 2000, Denef et al. 2004). On the basis of this experimental evidence, sequestration factors for reduced and no-tillage management have been developed (Ogle et al. 2005) and implemented for inclusion in the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories (IPCC 2006) and values for C credits due to no-till management have been sanctioned by the Chicago Climate Exchange (CCX).

At the same time, it has been long recognized that **not all** soils respond positively in terms of gaining C under no-till – in particular, soils with an already high content of soil C and cropland soils in cool, moist climates often do not show increases in C content under no-till compared to plow tillage; for example, this has been found for several experimental sites in eastern Canada (Anger et al. 1997). The reasons for this lack of response to reduced tillage intensity is not yet clear, although preliminary results suggest that reduced decomposition rates of buried residues under cool, moist climates and 'saturation' of physically-protected soil organic C in high C soils are potential mechanisms (E. Gregorich, personal communication; D. Angers, personal communication). However, the large majority of cropland soils in the US do not fall into this category.

Recently, a few researchers have raised questions about whether no-till, in general, actually leads to a relative increase in soil carbon when viewed at whole soil level, as illustrated in the papers by Baker et al.[1] and Blanco-Canqui and Lal[2]. The foundation of

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[1] Baker, J.M., T.E. Ochsner, R.T. Veterea and T.J. Griffis. 2007. Tillage and soil carbon sequestration: What do we really know? ***Agriculture, Ecosystems and Environment*** 118:1-5.

their arguments lay largely in the fact that most measurements of no-till vs tillage systems in long-term experiments have often only measured the top 30 cm or less of the soil profile, although several sites have been measured to depths of up to 100 cm. These authors argue that if soil carbon contents are summed to a greater depth of the soil profile (e.g the top 0 to 60 or 100 cm) then in most cases there is no statistically significant difference between different tillage systems. The problem with this argument is two-fold. First, it **is** true that the effects of no-till adoption **are** typically manifested in the top 20-30 cm of soil, which is the zone of soil disturbance in a tilled system! The vast majority of tillage comparisons show no significant differences in soil carbon content below the tillage zone (Ogle et al. 2005).[3] Secondly, because the change in soil C due to tillage management (the 'signal') is relatively small relative to the 'background' soil C content (the 'noise'), by adding in the additional C stored in lower parts of the profile (even if differences below the plow layer are not significant), this calculation increases the 'noise' in the estimate such that the signal-to-noise ratio decreases and thus it is not surprising that comparisons of C content for the entire soil profile are often not significantly different. A more meaningful determination is to utilize, as far as possible, measurements for different soil depth increments to the full depth of the soil profile and then to evaluate whether soil C contents are different below the tillage zone, and if not, then the estimates should be based on the measurements encompassing the depth of tillage, where the main effects of tillage management are manifested. This is the procedure that has been used in developing the IPCC soil C change factors for tillage management (IPCC, 2006).

Other data that has been used to question whether no-till really increases soil carbon are total ecosystem C flux from eddy covariance measurements (Baker et al. 2007). While eddy covariance (EC) techniques are a highly useful approach in C cycling research, there are several drawbacks which make them inappropriate for drawing inference about soil C changes. First, there are only (to our knowledge) 2-3 locations in the U.S. where EC is being used to estimate ecosystem C balances for systems under no-till (Baker et al., Verma et al. 2005), thus any inferences made cannot be considered general for no-till systems. Secondly, EC measurements have so far been for the first 2-3 years following conversion to no-till, in other words, during the transition phase between conventional and no-till when soil C increases are expected to be lowest. Finally, the typical rates of C accumulation determined from long-term plot studies (e.g. 0.1 to 0.5 tonnes C per ha) are likely to be within the 'error' estimate for annual net C accumulation using EC methods, thus there is little confidence in the estimates obtained for **annual** soil C changes (furthermore, EC estimates to date are typically unreplicated, hence a true determination of the error associated with these annual C changes are not possible). Hence the best

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[2] Blanco-Canqui, H. and R. Lal. 2008. No-tillage and soil-profile carbon sequestration: An on-farm assessment. ***Soil Science Society of America Journal*** 72:693-701.

[3] Baker et al. (2007) argue that one way in which plowed soils could accumulate **more** C in deeper depths in the soil profile, compared to no-till, is if no-till results in a more superficial distribution of roots, such that comparatively more root residues are deposited in deeper soil zones under plow tillage. Unfortunately, there are very few measurements of root distributions comparing tilled and no-tilled systems – Baker et al. (2007) cite only one study (from Switzerland) showing a deeper root distribution under plow tillage. While this potential mechanism is worthy of further research, it does not merit rejecting the many long-term tillage comparisons showing no significant differences in soil C below the depth of tillage.

method for determining soil C changes due to changes in soil management practices (including tillage) is through careful soil measurements in which the **accumulated** change in soil C over several years can be accurately determined.

An important point raised by Blanco-Canqui and Lal (2008) is that we currently lack good data on tillage effects under actual on-farm conditions. Our best information on tillage impacts are from field experiments administered by land grant universities and by governmental research agencies (e.g. ARS)[4]. However, the approach taken in the paper by Blanco-Canqui and Lal – i.e., paired field ('across the fence') comparisons of tilled and no-till practices – involved a number of serious shortcomings. First, paired comparisons – because they lack a true control – have a high degree of uncertainty. Even if similar soil and slope conditions are chosen it is impossible to know if soil carbon contents were the same before a change in tillage practices occurred. Secondly, in on-farm comparisons it is difficult to isolate the effect of tillage from other management variables. In most of the comparisons described by Blanco-Canqui and Lal (2008), crop rotations and nutrient management, as well as tillage, were different within the paired comparisons – hence apparent differences between fields cannot, in fact, be attributed to tillage. As the authors themselves point out, several of the apparent tillage differences, if real, are likely due to factors other than tillage, e.g., from pg. 697, "Unlike the NT [no-till] field, however, the PT [plow tillage] field was under winter wheat and rye cover crops, which were plowed under every year. Thus we hypothesize that the higher SOC [soil organic carbon] with PT may have been due to the use of cover crops. In MLRA 124, the higher SOC with PT may have been due to the use of continuous corn, a high biomass-producing crop, in contrast with the corn-soybean-alfalfa rotation in the NT field. Annual burying of coarse corn residues in PT soils may have increased SOC at lower depths compared with the relatively low-biomass-producing rotation adopted in NT farming".

Instead of using unreliable paired comparisons, new measurements of soil C change under actual on-farm conditions should be based on a resampling over time of on-farm benchmark sites, as part of a nationwide soil C monitoring network. Such a network is currently under development as part of the National Resources Inventory (NRI) administered by USDA-NRCS (J. Goebel, personal communication). Resources to establish and build out this network should be a high priority. In the meantime, our data from existing long-term field experiments provides the best source of knowledge about tillage (and other management) effects on soil C – here, the preponderance of evidence supports the conclusion that adoption of no-tillage increases soil C, relative to conventional tillage, in most US cropland soils.

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[4] However, it should be pointed out that the vast majority of agricultural field research being used for management and policy decisions in other areas (e.g. on genetics, yield, nutrient management, etc.) is also derived from controlled field research settings, and not from on-farm studies.

References

Angers, D.A., M.A. Bolinder, M.R. Carter, E.G. Gregorich, C.F. Drury, B.C. Liang, R.P. Voroney, R.R. Simard, R.G. Donald, R.P. Beyaert and J. Martel. 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. ***Soil Tillage Res***. 41:191-201.

Baker, J.M., T.E. Ochsner, R.T. Veterea and T.J. Griffis. 2007. Tillage and soil carbon sequestration. What do we really know? ***Agriculture, Ecosystems and Environment*** 118:1-5.

Blanco-Canqui, H. and R. Lal. 2008. No-tillage and soil-profile carbon sequestration: An on-farm assessment. ***Soil Science Society of America Journal*** 72:693-701.

Denef, K., J. Six, R. Merckx, and K. Paustian. 2004. Carbon sequestration in microaggregates of no-tillage soils with different clay mineralogy. ***Soil Science Society of America Journal*** 68:1935-1944.

IPCC (Intergovernmental Panel on Climate Change). 2006. **2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme,** Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Ogle, S.M., F.J. Breidt and K. Paustian. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. ***Biogeochemistry*** 72:87-121.

Paustian, K., O. Andren, H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. van Noordwijk and P. Woomer. 1997. Agricultural soil as a C sink to offset CO_2 emissions. ***Soil Use and Management*** 13:230-244.

Six, J., Elliott, E.T. and Paustian, 2000. K. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. ***Soil Biology & Biochemistry*** 32:2099-2103.

Six, J., S.M. Ogle, F.J. Breidt, R.T. Conant, A.R. Mosier and K. Paustian. 2004. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. ***Global Change Biology*** 10:155-160.

Verma, S.B., A. Dobermann, K.G. Cassman, D.T. Walters, J.M. Knops, T.J. Arkebauer, A.E. Suyker, G.G. Barba, B. Amos, H. Yang, D. Ginting, K.G. Hubbard, A.A. Gitelson and E. A Walter-Shea. 2005. Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems. ***Agri. Forest. Meteror***. 131:77-96.