EXTENDED ABSTRACT 19.6

Changes in Soil Organic Carbon and Nitrogen as a Result of Cultivation

W.M. POST and L.K. MANN

Environmental Sciences Division, Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 1000, Oak Ridge, Tennessee 37831-6335, USA

ABSTRACT

We assembled and analyzed a data base of soil organic carbon and nitrogen information from over 1100 profiles in order to explore factors related to the changes in storage of soil organic matter resulting from land conversion. The relationship between cultivated and uncultivated organic carbon and nitrogen storage in soils can be described by regression lines with uncultivated storage on the abscissa, and cultivated storage on the ordinate. The slope of the regression lines is less than 1 indicating that the amount of carbon or nitrogen lost is an increasing fraction of the initial amount stored in the soil. Average carbon loss for soils with high initial carbon is 23% for 1-meter depth. Average nitrogen loss for the same depth is 6%. In addition, for soils with very low uncultivated carbon or nitrogen storage, cultivation results in increases in storage. In soils with the same uncultivated carbon contents, profiles with higher C:N ratios lost more carbon than those with low C:N ratios, suggesting that decomposition of organic matter may, in general, be more limited by microbial ability to break carbon bonds than by nitrogen deficiency.

Because of increasing concern about atmospheric levels of CO_2, the role of soil in storing and releasing organic C must be more accurately assessed (Houghton et al., 1987). We need to be able to extrapolate in a systematic way from comparisons of C storage in cultivated and uncultivated soil samples to C losses at the landscape level. Although there is an abundance of literature quantifying losses of C due to cultivation, coverage of major agricultural soils has been uneven (Schlesinger, 1985; Mann, 1986). Our approach was to assemble a large data base and determine whether any general patterns of C and N storage changes as a result of cultivation could be inferred.

We have used statistical analyses to derive general estimates of changes in C and N storage across a broad range of soil types and amounts of organic matter. Data used in these analyses are from two types of sources - published paired plot studies and survey pedon data from the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) National Soils Analytical Laboratory. A critical part of the analysis was determining the suitability of the SCS data for quantifying changes due to land use. By comparing organic C and N storage in cultivated and uncultivated pedons within the same soil series, we

Soils and the Greenhouse Effect. Edited by A.F. Bouwman

hypothesized that we would be able to predict changes in soil organic C storage on a regional basis.

We extracted from the literature 625 "paired plots." Paired plots were carefully selected cultivated and uncultivated sites that were assumed to be similar before cultivation and were usually contiguous or close to one another. The data from the SCS files were not collected for the purpose of cultivated-uncultivated comparisons. Instead, they represent survey samples which we handled in the following manner. For each soil series, profile data were divided into two groups - cultivated and uncultivated. Pedons were considered cultivated if they had an Ap horizon at the surface and if vegetation was either row crop or pasture. The data for each soil series group were averaged to form a cultivated-uncultivated pair. Data from over 800 profiles were used to calculate 120 soil series pairs representing major agricultural soils in the United States. Despite variation introduced by a lack of control of sample locations, by limited sample numbers, and by limited information on past cultural treatments, regression analysis showed the SCS data to be similar enough to literature paired-plot data to be treated as samples from the same population.

Soils high in C and N tended to lose the largest amounts when cultivated. Soils low in C and N showed gains, though these gains were not consistent. That is, when gains occurred, they were not statistically significant. Cultivated C or N storage at 15, 30, or 100 cm can each be represented as a linear functions of uncultivated C and N (Figure 19.6.1). At low initial amounts, cultivation increases both C and N. Above a certain threshold (a different one for each element and depth considered) fractional loss of C or N caused by cultivation increases with the initial content. The estimated maximum loss of C resulting from cultivation is 29% for 0 to 15 cm, 22% for 0 to 30 cm, and 23% for 0 to 100 cm. Mean changes in C storage for soil orders demonstrated the overall pattern of change in C storage, with cultivation showed by pedon pairs. Means for Aridisols and Inceptisols, however, appeared to be slightly different from the overall pattern. For all soil orders the estimated maximum losses for N are 8% for 0 to 15 cm, 4% for 0 to 30 cm, and 6% for 0 to 100 cm. Average N changes are approximately one-fourth the corresponding C changes at all depths.

In the top 15 cm of uncultivated soils C:N ratios range from a mean of 12 in Mollisols to a mean of 22 in Ultisols (Figure 19.6.2). After cultivation, the range in surface-soil C:N ratio narrows, with most soil means ranging between 11 and 14. Some of the reduction from high C:N ratios to lower ones at the surface is caused by mechanical mixing of deeper soil (which usually has a lower C:N ratio) with the surface soil. This, however, can explain only a small portion of the changes observed. From the data we can infer changes in production and decomposition rates of different classes of organic matter.

The highest surface levels of N occur in Mollisols. These soils also have high amounts of C, but C:N ratios are low. In comparison with the usually forested soils (e.g., Alfisols, Ultisols, etc.), these prairie soils support productive vegetation that produces litter with high N contents and low lignin contents (high litter quality). After cultivation, both C and N are lost to the same extent, so C:N ratios are approximately the same. Soils that support native woody vegetation have a different

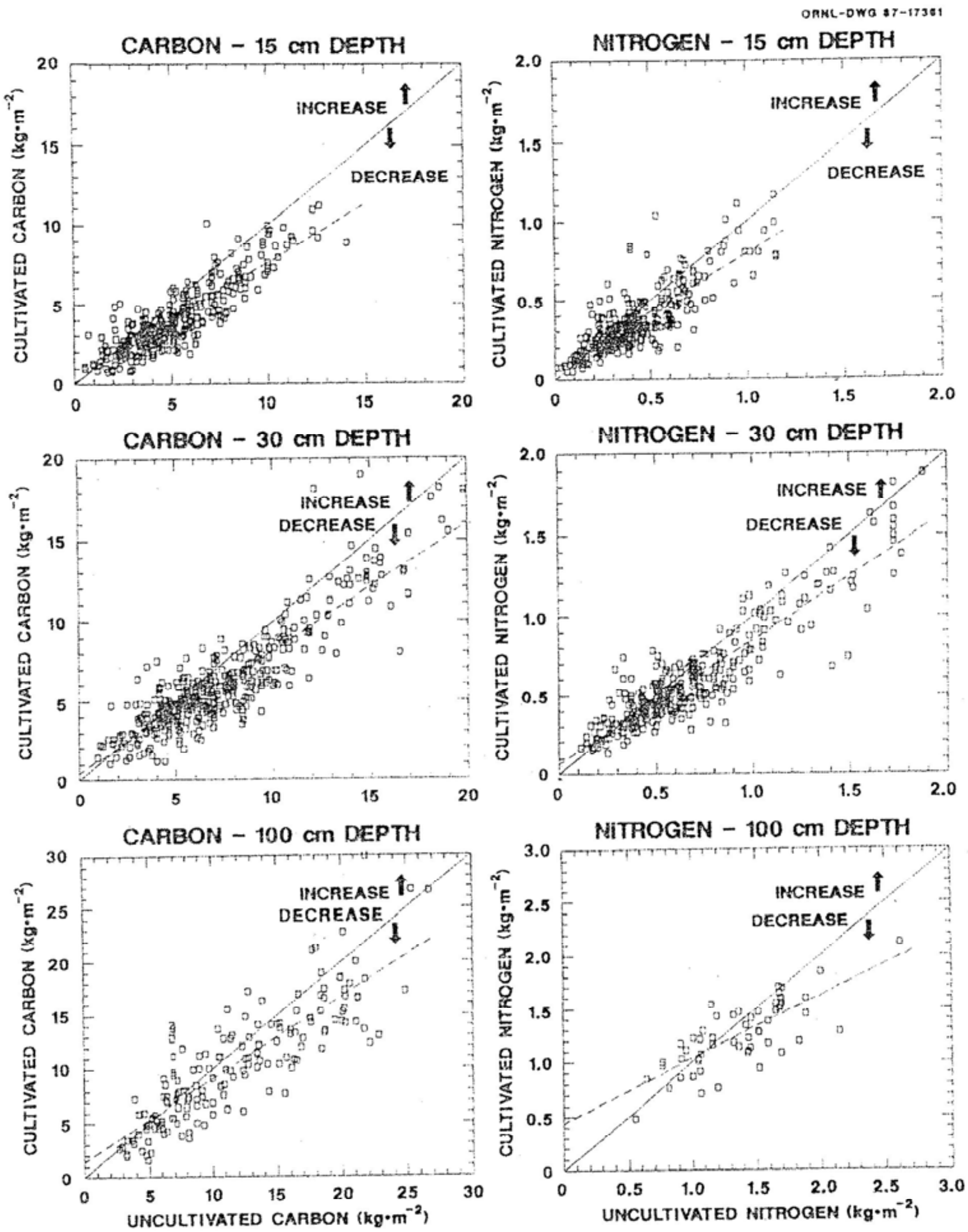

Figure 19.6.1 The relationship betwen carbon or nitrogen storage in the surface to a depth of 15, 30, and 100 cm before and after cultivation. A solid line indicates points of no change; a dashed line indicates the linear regression line.

pattern, which is most clearly seen in Ultisols. Here, C:N ratios are large (average C:N = 20.9) because of the production of low-quality leaf litter and woody material that decompose slowly. After cultivation, the C:N ratio is significantly lower (average C:N = 14.7). During this process, very little N is lost while organic C is converted to CO_2. If the mean uncultivated C:N ratio for a soil series is plotted as the abscissa, and the mean cultivated C:N ratio of a soil series is plotted as the ordinate, the 1:1 line is the set of points where uncultivated C:N = cultivated C:N. Mollisols are clustered near the 1:1 line with C:N = 12 (Figure 19.6.2). Other soil groups show significant reductions in C:N ratio with cultivation and lie largely below the 1:1 line. There is also a tendency for the variance of C:N ratios to decrease. As a result, cultivated soil C:N ratios lie in a narrower range than uncultivated ones.

The interactions between vegetation and climate determines litter quality, vegetation productivity, and decomposition rates (Meentemeyer, 1978; Melillo et al., 1982; Pastor et al., 1984; Parton et al., 1987). These in turn determine C and N storage in these various soil organic matter pools, as well as the interactions between C and N (Post et al., 1982, 1985; Wessman et al., 1988). Excluding Vertisols, for which we do not have a sufficient number of samples for adequate analysis, Mollisols

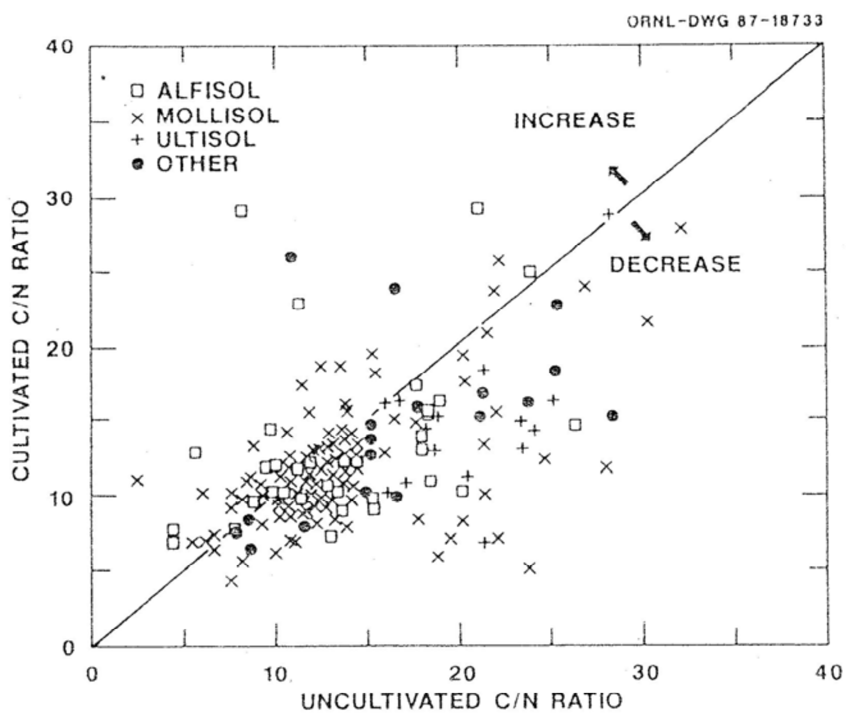

Figure 19.6.2 The relationship between carbon/nitrogen ratios in the surface depth of 15 cm before and after cultivation. A solid line indicates points of no change.

show the greatest accumulation of C and N. Organic matter in these soils is derived from high-quality litter, low in lignin and high in N. Cultivation results in loss of organic matter but not much change in the C:N ratio. Organic matter in forest soils, on the other hand, is derived from lignified woody material that is of low litter quality and contains high C:N ratios. As a result, these soils have a larger proportion of material in a slowly decomposing organic matter fraction (with higher C:N ratios) than in an actively decomposing fraction. Conversion to cultivation results in significant reduction of C:N ratios, which indicates compositional changes in soil organic matter, probably a significant reduction of a slowly decomposing organic matter fraction. This pattern is particularly striking in highly weathered soils such as Ultisols. Less-weathered forest soils such as Alfisols are intermediate between Ultisols and Mollisols. Soils that are initially very low in organic matter because of climatic factors (Aridisols), show gains in C and N upon cultivation.

Initial N content or concentration in relation to C does not contribute much to the variation in the magnitude of C change after conversion to agriculture, except that in soils with very high C:N ratios, more C may be mineralized than in soils with low C:N ratios. This contradicts the hypothesis that N enhances C loss by facilitating decomposition by microorganisms. Rather, it appears that microbial activity is, in general, C-limited. Replacement of forests by crops results in a change in litter: woody material with a high proportion of slowly decomposing organic matter is replaced by herbaceous crops with a lower proportion of slowly decomposing organic matter. The net effect is that the slowly decomposing organic matter fraction in soils where there were large inputs to the slow fraction from native woody vegetation is reduced by conversion to more herbaceous crop material that produces litter with lower lignin:N ratios. This reduces high C:N ratios so that eventually all C:N ratios in cultivated soils converge on the ratio typical of prairie soils (agricultural crops and pastures can be thought of as producing litter similar in quality to prairie vegetation). The final organic matter content is then determined by the microorganism activity that is related to soil-forming factors independent of initial N concentration. Thus, decomposition of recalcitrant organic matter is probably not significantly accelerated, but over a long time (50 to 100 years) organic matter will eventually be reduced and not be replenished by sufficiently large additions of new recalcitrant organic matter to maintain this important pool of organic matter.

ACKNOWLEDGEMENTS

Research sponsored by the U.S. Department of Energy, Carbon Dioxide Research Program, Ecological Research Division, Office of Health and Environmental Research, Budget Activity Number KP 05 00 00 0, and the National Science Foundation's Ecosystem Studies Program under

Interagency Agreement BSR-8417923, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. Publication No. 3412, Environmental Sciences Division, Oak Ridge National Laboratory.

REFERENCES

Houghton, R.A., R.D. Boone, J.R. Fruci, J.E. Hobbie, J.M. Melillo, C.A. Palm, B. Peterson, G. Shaver, G.M. Woodwell, B. Moore, D.L. Skole and N. Myers (1987) The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: Geographic distribution of global flux. Tellus 39B:122-39.

Mann, L.K (1986) Changes in soil carbon storage after cultivation. Soil Science 142:279-88.

Meentemeyer, V. (1978) Macroclimate and lignin control of litter decomposition rates. Ecology 59:465-72.

Melillo, J.M., J.D. Aber and J.F. Muratore (1982) Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63:621-26.

Parton, W.J., D.S. Schimel, C.V. Cole and D.S. Ojima (1987) Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal 51:1173-79.

Pastor, J., J.D. Aber, C.A. McClaugherty and J.M. Melillo (1984) Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. Ecology 65:256-68.

Post, W.M., W.R. Emanuel, P.J. Zinke and A.G. Stangenberger (1982) Soil carbon pools and world life zones. Nature 298:156-59.

Post, W.M., J. Pastor, P.J. Zinke and A.G. Stangenberger (1985) Global patterns of soil nitrogen. Nature 317:613-16.

Schlesinger, W.H. (1985) Changes in soil carbon storage and associated properties with disturbance and recovery. In J. R. Trabalka and D. E. Reichle (eds.), The Changing Carbon Cycle: A Global Analysis. Springer-Verlag, New York.

Wessman, C.A., J.D. Aber, D.L. Peterson and J.M. Melillo (1988) Remote sensing of canopy chemistry and nitrogen cycling in temperate forest ecosystems. Nature 335:154-56.