Available online at www.sciencedirect.com
SCIENCE DIRECT®
Applied Soil Ecology 30 (2005) 174–191
Applied Soil Ecology
www.elsevier.com/locate/apsoil

Soil carbon and nitrogen changes as affected by tillage system and crop biomass in a corn–soybean rotation

Mahdi M. Al-Kaisi *, Xinhua Yin, Mark A. Licht

Department of Agronomy, Iowa State University, Ames, IA 50011-1010 USA

Received 13 September 2004; accepted 23 February 2005

Abstract

A wide range of tillage systems have been used by producers in the Corn-Belt in the United States during the past decade due to their economic and environmental benefits. However, changes in soil organic carbon (SOC) and nitrogen (SON) and crop responses to these tillage systems are not well documented in a corn–soybean rotation. Two experiments were conducted to evaluate the effects of different tillage systems on SOC and SON, residue C and N inputs, and corn and soybean yields across Iowa. The first experiment consisted of no-tillage (NT) and chisel plow (CP) treatments, established in 1994 in Clarion–Nicollet–Webster (CNW), Galva–Primghar–Sac (GPS), Kenyon–Floyd–Clyde (KFC), Marshall (M), and Otley–Mahaska–Taintor (OMT) soil associations. The second experiment consisted of NT, strip-tillage (ST), CP, deep rip (DR), and moldboard plow (MP) treatments, established in 1998 in the CNW soil association. Both corn and soybean yields of NT were statistically comparable to those of CP treatment for each soil association in a corn–soybean rotation during the 7 years of tillage practices. The NT, ST, CP, and DR treatments produced similar corn and soybean yields as MP treatment in a corn–soybean rotation during the 3 years of tillage implementation of the second experiment. Significant increases in SOC of 17.3, 19.5, 6.1, and 19.3% with NT over CP treatment were observed at the top 15-cm soil depth in CNW, KFC, M, and OMT soil associations, respectively, except for the GPS soil association in a corn–soybean rotation at the end of 7 years. The NT and ST resulted in significant increases in SOC of 14.7 and 11.4%, respectively, compared with MP treatment after 3 years. Changes in SON due to tillage were similar to those observed with SOC in both experiments. The increases in SOC and SON in NT treatment were not attributed to the vertical stratification of organic C and N in the soil profile or annual C and N inputs from crop residue, but most likely due to the decrease in soil organic matter mineralization in wet and cold soil conditions. It was concluded that NT and ST are superior to CP and MP in increasing SOC and SON in the top 15 cm in the short-term. The adoption of NT or CP can be an effective strategy in increasing SOC and SON in the Corn-Belt soils without significant adverse impact on corn and soybean yields in a corn–soybean rotation.

Keywords: Carbon input; Corn; Soil organic carbon; Soil organic nitrogen; Soybean; Tillage; Yield

Abbreviations: CNW, Clarion–Nicollet–Webster; GPS, Galva–Primghar–Sac; KFC, Kenyon–Floyd–Clyde; M, Marshall; OMT, Otley–Mahaska–Taintor; SOC, soil organic C; SON, soil organic N

* Corresponding author. Tel.: +1 515 294 1923; fax: +1 515 294 9985.
E-mail address: malkaisi@iastate.edu (M.M. Al-Kaisi).

0929-1393/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsoil.2005.02.014

1. Introduction

Soil organic C (SOC) and N (SON) are important in sustaining soil quality, promoting crop production, and protecting the environment (Bauer and Black, 1994; Doran and Parkin, 1994; Robinson et al., 1994) due to their effects on water retention, soil aeration, nutrient cycling, and plant root growth (Sainju and Kalisz, 1990; Sainju and Good, 1993). Carbon and N losses from soil to the atmosphere as gases due to natural and management-induced causes can contribute to global warming (Reicosky, 1997a,b). However, soil can also function as a net sink for sequestering atmospheric CO_2 through appropriate soil and crop management, and thus attenuating the increase in atmospheric CO_2 (Paustian et al., 1992; Lal et al., 1995).

It has been well documented that soil can be managed to increase SOC and SON storage from a long-term (>10 years) perspective by implementing conservation soil and crop management practices such as conservation tillage (Havlin et al., 1990; Franzluebbers et al., 1995; Halvorson et al., 2002) and crop rotations (Robinson et al., 1996). In contrast, intensive tillage can reduce the storage of these two components, because it incorporates crop residue into the soil, disrupts soil aggregates, and increases soil aeration (Dalal and Mayer, 1986; Balesdent et al., 1990; Cambardella and Elliott, 1993). However, short-term (≤10 years) management effects on soil C and N dynamics are complex and often variable. After analyzing a large global data set, West and Post (2002) concluded that soil C sequestration was generally increased by no-tillage (NT) practices, but had a delayed response, with peaks in years 5–10. This finding agreed with the results reported by Franzluebbers and Arshad (1996) that there may be little to no detectable increase in SOC in the first 2–5 years, but a large increase 5–10 years after switching to conservation tillage. In a study on short-term crop rotation effects on SOC, Campbell et al. (2000) found that measurable gain in SOC could be observed in six years or less when weather conditions were favorable.

Conservation tillage systems such as NT and strip-tillage (ST) have been increasingly used for crop production in the Corn-Belt during the past decade due to their significant environmental advantages over moldboard plow (MP). For example, NT systems in the Midwest were used in over 22% of all cropland area in 2002 (Conservation Technology Information Center, 2003), which almost doubled that in 1992. Deep rip (DR) is another tillage system used widely under the assumption of correcting soil compaction and increasing crop yields in the Corn-Belt. Although DR is not a conservation tillage system, it still results in less soil disturbance and mixing and greater crop residue coverage on the soil surface than moldboard plow. There have been few studies that quantify the effects of these major tillage alternatives on soil C and N changes and residue C and N inputs compared with MP in the Corn-Belt soils where a corn–soybean rotation is the primary cropping system.

Effects of soil and crop management practices on SOC and SON changes, in part, depend on soil properties and environmental factors, such as soil texture, clay mineralogy, topography, and climate (Janssen, 1984; Bohn et al., 1985; Campbell et al., 1999). Therefore, understanding the effects of management practices on SOC and SON of major soils in a specific agro-ecological and production area is essential in developing best management practices and prediction tools for SOC and SON management. Tillage practices and crop residue management can play a significant role in replenishing SOC and SON, but plant materials contain a wide range of C and N compounds that have different decomposition rates affected by many soil factors (Ajwa and Tabatabai, 1994). Thus, changes in soil moisture, temperature, oxygen content, pH, nutrient availability, and other soil factors can alter the decomposition rates of plant biomass and the mineralization rate of soil organic matter (Broadbent et al., 1964; Kowalenko et al., 1978; Clark and Gilmour, 1983). The question is whether short-term (≤10 years) implementation of conservation tillage practices and crop residue have advantages over conventional tillage in increasing SOC and SON sequestration in a corn–soybean rotation. Therefore, the primary objective of this study was to examine the short-term effects of major tillage alternatives on SOC and SON changes with depth, aboveground residue biomass C and N inputs, and corn and soybean yields compared with conventional tillage in a corn–soybean rotation.