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Soil quality response to tillage and crop residue removal under subarctic conditions

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Abstract

Little is known about the long-term effects of tillage and crop residue management on soil quality and organic matter conservation in subarctic regions. Therefore, we quantified wet aggregate stability, bulk density, pH, total organic C and N, inorganic N, microbial biomass C and N, microbial biomass C:N ratio, microbial quotient, and potential C and N mineralization for a tillage/crop residue management study in central Alaska. Soil from no-till (NT), disked once each spring (DO), and disked twice (DT, spring and fall) treatments was sampled to 20 cm depth in spring and fall of the 16th and 17th years of the study. Crop residues were either retained or removed after harvest each year. Reducing tillage intensity had greater impact on most soil properties than removing crop residues with the most notable effects in the top 10 cm. Bulk density was the only indicator that showed significant differences for the 10–20 cm depth, with values of 0.74 Mg m^{-3} in the surface 10 cm in NT compared to 0.86 in DT and 1.22 Mg m^{-3} in NT compared to 1.31 in DT for the 10–20 cm depth. Wet aggregate stability ranged from 10% in DT to 20% in NT. Use of NT or DO conserved soil organic matter more than DT. Compared to measurements made in the 3rd and 4th years of the study, the DT treatment lost almost 20% of the soil organic matter. Retaining crop residues on the soil conserved about 650 g m^{-2} greater C than removing all residues each year. Soil microbial biomass C and mineralizable C were highest in NT, but the microbial C quotient, which averaged only 0.9%, was not affected by tillage or crop residue treatment. Microbial biomass C:N ratio was 11.3 in DT and 14.4 in the NT, indicating an increasing predominance of fungi with decreasing tillage intensity. Barley grain yield, which averaged 1980 kg ha^{-1} over the entire 17 years of the study, was highest in DO and not significantly different between NT and DT, but weeds were a serious problem in NT. Reduced tillage can improve important soil quality indicators and conserve organic matter, but long-term NT may not be feasible in the subarctic because of weed problems and build up of surface organic matter.

Keywords: Tillage; Crop residue management; Subarctic; Soil quality; Soil organic matter

1. Introduction

Soil degradation is a concern in interior Alaska because soils are often shallow and form very slowly due to low annual temperature and relatively long winter. Also, many of the soils under agriculture in the region are moderately to severely susceptible to erosion (Schoephorster, 1973). Thus, management practices must provide protection against degradation of these soils. Conservation tillage can play an important role in minimizing soil erosion and improving soil quality in the region. For example, Knight and Lewis (1986) found that aggregates were more stable under no tillage (NT) than under more intensive tillage in a 3-year study in subarctic Alaska. Sharratt (1996) reported that NT improved soil physical properties compared to intensive tillage (disked in spring and fall each year) and straw maintained on the surface conserved water and promoted mechanical stability of soil aggregates in the 7th year of study.

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Numerous studies in temperate regions have shown that decreasing tillage intensity or increasing amount of surface residues retained on the soil surface results in higher organic C and N and improved soil quality (Bruce et al., 1990; Lal et al., 1994; Heeman et al., 1995; Salinas-Garcia et al., 1997; Soon et al., 2001; Halvorson et al., 2002a,b). Some have reported higher soil organic matter levels near the surface but not in the total profile (Needelman et al., 1999) and others have shown changes in concentration but not of mass (on an area basis) of organic matter and its components (Campbell et al., 1996).

We hypothesized that reducing or eliminating tillage and retaining crop residues would result in improvements in soil quality (as reflected by various soil properties) and conserve or increase soil organic matter in a subarctic soil. Our objectives were to determine the effects of long-term tillage and crop residue management practices on various soil physical, chemical, and biological properties in central Alaska.

2. Materials and methods

2.1. Site description and experimental design

A long-term tillage and crop residue management study was established on a Volkmar silt loam (coarse-silty over sandy or sandy skeletal, mixed, superactive Aquic Eutrocryepts) at the University of Alaska Fairbanks Delta Field Research Site (63°55′N, 145°20′W) near Delta Junction in central Alaska (Lewis and Cullum, 1985). The area is characterized by a semi-arid, strongly continental climate, with cold winters and cool summers (Table 1). Tillage treatments were: disked twice, once each spring and once each fall (DT); disked once each spring (DO); and NT, each with two crop residue treatments: straw and stubble removed after harvest in fall or all crop residues retained. Plots were fertilized each spring with 112 kg mono-ammonium phosphate, 112 kg potassium chloride, and 190 kg urea ha^{-1} to supply 100 kg N ha^{-1}, 30 kg P ha^{-1}, and 50 kg K ha^{-1} and cropped to barley (*Hordeum vulgare* L.). Three replications were laid out in a strip plot design with crops residue treatments oriented perpendicular to tillage treatments.

Table 1
Climatic conditions for Delta Junction, Alaska

Average annual precipitation (mm)	373
Average growing season (May–September) precipitation (mm)	233
Growing degree days (5 °C base temperature)	860
Average number of sequential days with air temperature remaining above 0 °C	55
Average number of sequential days with air temperature remaining above −5 °C	104

2.2. Soil sampling and analysis

We collected soil samples from the 0 to 10 cm depth (approximate tillage depth) and the 10–20 cm depth in the spring and fall of both the 16th and 17th years of the study. Samples were collected in the spring prior to any farming operations and in fall soon after harvest and before fall tillage. We also collected the accumulated surface litter from the NT treatments. Soil characteristics examined in this study are often considered sensitive indices of soil degradation and tools to help assess long-term sustainability of various soil management practices (Karlen et al., 1994; Saggar et al., 2001).

For wet aggregate stability, an indicator of resistance to soil erosion (Karlen et al., 1994), we collected three cores, each 4.5 cm in diameter, from the surface 10 cm of each plot. These samples were sieved through a 6-mm mesh screen at field moisture content prior to beginning the analysis. For bulk density, we collected separate core samples from the 0 to 10 and the 10 to 20 cm depths. For the top sample, we pushed a 15-cm diameter core 10 cm into the soil, excavated an area to the side of the core, and then carefully sliced off the bottom of the core with a serrated bread knife. This was to avoid compaction in the cores, which we observed previously when sampling this soil and to ensure accurate core volume. For the 10–20 cm depth, we sampled from the same hole as the surface sample with a 4.5-cm diameter-coring device. For all other soil properties, we collected 20, 1.5 cm diameter cores from the 0 to 20 cm depth in each plot. The cores were split into 0–10 and 10–20 cm depth segments.

For wet aggregate stability, we used the end-over-end shaker method described by Pojasok and Kay (1990). To determine soil bulk density, we oven dried and then weighed whole cores. We measured organic C and N by dry combustion in a CHN analyzer. Soil pH was determined with an electrometer equipped with a calomel reference electrode in a 1:1 soil:water suspension (Thomas, 1996). Ammonium and nitrate-N in soil was extracted in 2 M KCl solution and then analyzed colorimetrically with an automated rapid flow analyzer (RFA-300, Alpkem, Clackamas, OR). Soil microbial biomass C and N was estimated by the fumigation–extraction method (Vance et al., 1987). We measured mineralizable C and N using the methods described by Sparrow and Cochran (1988) for a 10-week incubation