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Soil carbon and nitrogen sequestration following the conversion of cropland to alfalfa forage land in northwest China

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Abstract

Soil C and N contents play a crucial role in sustaining soil quality and environmental quality. The conversion of annually cultivated land to forage grasses has potential to increase C and N sequestration. The objective of this study was to investigate the short-term changes in soil organic C (SOC) and N pools after annual crops were converted to alfalfa (*Medicago sativa* L. Algonguin) forage for 4 years. Soil from 24 sets of paired sites, alfalfa field versus adjacent cropland, were sampled at depths of 0–5, 5–10 and 10–20 cm. Total soil organic C and N, particulate organic matter (POM) C and N were determined. Organic C, total N, POM-C, and POM-N contents in the 0–5 cm layer were significantly greater in alfalfa field than in adjacent cropland. However, when the entire 0–20 cm layer was considered, there were significant differences in SOC, POM-C and POM-N but not in total N between alfalfa and crop soils. Also, greater differences in POM-C and POM-N were between the two land-use treatments than in SOC and total N were found. Across all sites, SOC and total N in the 0–20 cm profile averaged 22.1 Mg C ha^{-1} and 2.3 Mg N ha^{-1} for alfalfa soils, and 19.8 Mg C $ha^{-1}$and 2.2 Mg N ha^{-1} for adjacent crop soils. Estimated C sequestration rate (0–20 cm) following crops to alfalfa conversions averaged 0.57 Mg C ha^{-1} $year^{-1}$. Sandy soils have more significant C accumulation than silt loam soils after conversion. The result of this suggests that the soils studied have great C sequestration potential, and the conversion of crops to alfalfa should be widely used to sequester C and improve soil quality in this region.

Keywords: Carbon sequestration; Nitrogen sequestration; Particulate organic matter; Land use conversion; Alfalfa; Northwest China

1. Introduction

Soil organic carbon (SOC) plays a crucial role in sustaining soil quality, crop production and environmental quality (Doran and Parkin, 1994). This is due to its effects on soil physical, chemical and biological properties, such as soil water retention and availability, nutrient cycling, gas flux, plant root growth, and soil conservation (Gregorich et al., 1994). A loss of SOC due to inappropriate land use or the use of poor soil management or cropping practices can cause a decline in soil quality and potentially lead to emissions of C into the atmosphere (Lal, 2002). On the other hand, appropriate land use and soil management can lead to an increase in SOC, improve soil quality and partially mitigate the rise of atmospheric CO_2 (Paustian et al., 1997; Lal and Bruce, 1999; Lal, 2002).

Strategies for sequestering SOC into agroecosystems have been well documented (Lal and Bruce, 1999; Post and Kwon, 2000; Lal, 2002). These measures include converting degraded arable lands to perennial grasslands, implementing crop management practices such as conservation tillage, using highly diverse rotations, and introducing legumes and grass mixtures into the rotation cycle (Lal and Bruce, 1999; Lal et al., 1999;

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Lal, 2002). Of the practices, the conversion of cropland particularly marginal land to pasture or forage grass has the greatest potential for increasing C sequestration (Lal et al., 1999). Based on a world-wide survey, Conant et al. (2001) reported an average C sequestration rate of 1.01 Mg C ha^{-1} $year^{-1}$ when cultivated land was converted to pasture. Studies on the conversion of cultivated land to perennial grass through the conservation reserve program (CRP) in the US have documented increases in SOC from conversion to grass cover (Reeder et al., 1998; Uri and Bloodworth, 2000). Gebhart et al. (1994) estimated perennial grasses increased SOC at an average rate of 1.1 Mg C ha^{-1} $year^{-1}$ to a 3 m depth at selected CRP sites. In Canada, the use of forage-based rotation has markedly increased SOC content for over 70 years, despite the removal of C in forage or crop residues (Juma et al., 1997). Similar to the CRP in the US, a program of soil and water conservation called ''returning degraded land or marginal land to forest or grass'' has been implemented in erosion-prone areas across China in recent years. The program has been credited with substantial reductions in wind and water erosion of marginal croplands and is expected to significantly contribute to soil C sequestration. However, the effect of converting annual crops to perennial, forage crops on C sequestration is not well studied in China.

In recent years, accumulating evidence suggests that certain fractions of SOC are likely to respond more rapidly than total soil C to land use change and management. It has been shown that C and N presented in particulate organic matter (POM) can accumulate rapidly under land management systems that minimize soil disturbance and may also provide an early indicator of changes in C dynamics and total soil C under different land use and management practices (Cambardella and Elliott, 1992; Franzluebbers and Arshad, 1997; Franzluebbers and Stuedemann, 2002). Furthermore, differences in C fractions under different land use practices can yield important information about the mechanisms of C sequestration (Six et al., 2002). In addition, many C sequestration studies have also examined total soil N (Reeder et al., 1998; Bronson et al., 2004) because of its importance in C sequestration in agroecosystems (Reeder et al., 1998).

The objective of this research was to investigate the short-term changes in soil organic C and N pools, and POM-C and N fractions following the conversion of crop land to perennial alfalfa (*Medicago sativa* L. Algonguin) in northwest China.

2. Materials and methods

2.1. Study site

The study area was located on the Linze oasis in the middle reach of the Heihe River Basin, in Gansu province of northwest China, between 99°51′– and 100°30′E, 38°57′–39°42′N, which is an artificial oasis formed by drawing the water for irrigation from the Heihe River in different historical periods. The edge of the oasis is connected with dense moving and denudation residual sand dunes as well as Gobi. The climate is typified by cold winters and dry hot summers with an average annual temperature is 7.6 °C. Mean annual precipitation of 117 mm. Mean annual wind velocity is 3.2 m s^{-1}. Gales with wind velocity > 17 m s^{-1} occur 15 or more days per year. The main soil types are Aridsols and Entisols. Those soil types with long-term cultivation history (more than 100 years) include Fluvents and Ustochrepts are distributed around the bank of Heihe River, whereas the soils distributed on the edge of the oasis, with a relative short-term cultivation history (8–70 years) are Psamments and Typic Calciorthids, which have a loose structure and very low organic matter content, and are very susceptible to wind erosion. The staple crops of maize and spring wheat rely completely on irrigation water from the Heihe River.

2.2. Site selection

In 2000, a program of converting degraded cropland to forest or grass was implemented in this area and alfalfa was planted with the objective of increasing soil cover (to reduce wind erosion) and improve soil quality. The total area of cropland sown alfalfa grassland was about 2000 ha. At the beginning of the program, four soil types (Ustochrepts, Fluvents, Psamments and Typic Calciorthids) were selected. On each of these soil types, six sites were established and each site two treatments within the same farmland were established: continuous crop (maize) and conversion of maize to alfalfa. Each site within the same soil type was at least 500 m distance each other.

In late September of 2004, soil samples were collected in the 24 paired crop and alfalfa plots. Soil characteristics, land use and management, and experiment design are listed in Table 1.

2.3. Soil collection and analysis

On the alfalfa and adjacent corn areas of each site, 20 m × 30 m sampling plots were marked and soil