Annals of Arid Zone 41(2): 109-118, 2002

Characteristics of Soil Degradation as Affected by Long-term Land Use and Management Systems in a Semi-arid Sandy Soil in North China

Youngzhong Su and Halin Zhao
Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, P.R. China

Abstract: The conversion of natural grassland to cropland had resulted in severe deterioration in soil resource and rapid expansion of land desertification in the semi-arid agro-pastoral zone of north China. To assess the effects of land-use change and subsequent soil and crop management practices on soil degradation in semi-arid Horqin Sandy Land, north China, soils were sampled from adjacent natural grassland (NG) and cultivated land (converted from NG in 1986), including hawthorn (*Crataegus sanguinea* L.) orchard (HO), monocultured cropland (MC) and alley-cropping land (interpolating with plum trees and crops) (AC). Land use change and subsequent tillage practices resulted in significant decreases in silt content, water-holding capacity, dry macro-aggregate, organic C, total N, basal soil respiration, and phosphatase activities. However, contents of total and available P were improved by application of phosphorus fertilizers in cultivated systems. Compared with NG soil, the extent of soil degradation in the cultivated system was ranked in the order: the conventional tilled cropland (MC) > the tilled alley-cropping system (AC) > the HO pattern with minimized disturbance. From perspective of soil resource and environment conservation, a viable option for protecting soil resources and achieving sustainable land use should be to stop conversion of grassland to cropland and to translate the conventional tillage into conservation tillage.

Key words: Land use change, soil management, soil properties, soil degradation, Horqin Sandy Land, north China.

In many parts of north China, especially in the semi-arid agro-pastoral zone, the natural grasslands have suffered profound land-use transformation during the past decades (Wang, 2000). As direct and indirect consequences of land use changes, conversion of natural grassland to cropland destroyed grassland sod that protected the soil and accelerated soil erosion by wind (Xu *et al*., 1993), and in turn resulted in destruction of soil structure, decline in soil C and nutrients (Xiao *et al*., 1998; Wang *et al*., 1988), and depletion of some biological properties (Saviozzi *et al*., 2001). In recent decades, indiscriminate conversion of natural grassland to cropland and subsequent adoption of inappropriate soil and crop management practices led to rapid expansion of land degradation in the semi-arid region of north China (Zhao *et al*., 2000). Severe soil degradation/desertification is not only reducing the sustainability and productivity of agricultural systems, but also deteriorating both local and off-site eco-environments. However, relatively little is known about the soil degradation as affected by long-term crop management systems in erosion-prone sandy soils in the semi-arid parts of north China. Information about the effects of long-term soil and crop management systems on soil properties is important for a better understanding of the processes and mechanisms of soil degradation and for appropriate management to conserve the land resources.

The impact of land use and management systems on the degree of soil degradation can be evaluated by comparing selected soil physical, chemical and biological properties (Wang and Gong, 1988; Islam and Weil, 2000). Soil organic C and nutrients generally decline when grasslands in semi-arid regions are brought under cultivation. Land use pattern, tillage methods, and cropping systems affect the rate of this decline (Unger, 1977). Organic C is an important indicator to quantify the effects of land use and management on soil degradation (Lal, 1997). In wind erosion-prone sandy land systems, the deterioration of soil structure due to removal of fine particles by wind is generally significant. The characteristics of soil particle size fractions might provide useful indicators of wind erosion (Lobe *et al*., 2001). A number of researchers in recent years suggested that soil basal respiration and enzyme activities can be regarded as potential indicators of soil quality because of their essential role in soil biology and rapid response to changes in soil management (Dick *et al*., 1996). Soil enzyme activities also respond to agronomic practices such as fertilizers, amendments, and vegetation cover (Gianfreda and Bollage 1996), and to conservation practices (Bergstrom *et al*., 1998). We examined soils in four adjoining ecosystems under protectively grazed natural grassland (NG) and cultivated land (converted from natural grassland in 1987) that was subjected to different uses and managements, including hawthorn orchard (HO), wheat-maize rotation cropland (WC) and alley-cropping land (interplanted with plum trees and crops) (AC) in the semi-arid Horqin Sandy Land of north China. The objectives of this study were to investigate the influence of land use change and that of different land use and management practices on soil physical, chemical and biological properties.

Materials and Methods

Study area

The study was conducted at the Naiman Desertification Research Station (NDRS), Chinese Academy of Science, in Naiman Country (42°55′N, 120° 42′E, 345 m above mean sea level) in the eastern part of Inner Mongolia, China. Naiman is located in the south-west end of the Horqin Sandy Land and has a continental semi-arid monsoon climate in the temperate zone. According to data (1961-2000) from the Naiman Weather Station, the annual mean air temperature is about 6.8°C. The coldest and warmest monthly mean temperatures are –13.1°C in January and 23.7°C in July, respectively. The annual mean accumulated temperature above 10°C is 3190°C, and the annual mean precipitation is 366 mm, with a strong seasonal variability. The frost-free period is in the range of 130 to 150 days per year, while the annual mean wind speed is 3.4 m s^{-1}, with frequent occurrence of gales (wind speed >20 m s^{-1}) in winter and spring. Geomorphologically the region is characterized by sand dunes alternating with gently undulating interdune areas. The zonal soils are degraded Orthi-Sandic Entisols according to the Chinese soil classification system (Chinese Soil Taxonomy Cooperative Research Group, 1995), and are characterized by coarse texture and loose structure. Soils are highly susceptible to wind erosion, particularly on cultivated lands.

The experimental sites were the observation fields belonging to the NDRS. Salient characteristics of the experimental sites are described below.

NG was dominated by *Artemisia scopaia* L., *Cleisogenes squarrosa* L. and *Lespedeza dahurica* L., and the vegetation cover was 80%. HO is an orchard of *Crataegus sanguinea* L., with a density of 450 trees ha^{-1} and had perennial alfalfa planted under closed canopy (converted from natural grassland in 1986). AC had inter-cropping with plum trees and spring wheat, soybean, buckwheat, etc., where the tree row space was 8 m (converted from natural grassland in 1986). MC had monoculture of spring wheat and maize (converted from natural grassland in 1986).

The sites were farmed conventionally according to local usage. The NG was protectively grazed. The HO was irrigated 3 to 4 times each year, grasses under the closed canopy were mowed occasionally for livestock forage, and fallen leaves were removed each year for pest control. The AC site was interplanted with wheat, soybean and buckwheat, and the MC site was cultivated with a rotation of spring wheat and maize, and occasionally soybean for 15 years. All cropping sites were conventionally ploughed to a depth of 15 to 20 cm using a mouldboard plough, followed by leveling and rolling, discing and power harrowing. The cropping sites were also irrigated 3 to 4 times each year. All above-ground crop residues of AC and MC sites were removed after harvest. Inorganic fertilizers were applied regularly (70 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} in HO and 3 kg P_2O_5 ha^{-1} in MC). About 1500 kg ha^{-1} farmyard manure was also applied annually in the three sites. The natural grassland was never irrigated and no fertilizer was applied.

Soil sampling

In all the plots samples were collected from 0 to 15 cm depth in April 2002. Within each field (about 100 x 150 m area), five subsites (20 x 20 m) were divided and five bulk samples were collected, each consisting of ten 500 g subsamples. A bulk sample of AC site consisted of 5 subsamples taken under the tree canopy and 5 subsamples taken from cultivated alleys. In addition, five samples were taken in stainless steel cylinders (100 cm^3) in each subsite to determine the bulk density. Soil samples were placed in plastic bags. In the laboratory, each soil sample was thoroughly mixed, and part of each mixed sample was used to determine aggregate, and other part was passed through a 2 mm steel sieve. Part of each sieved soil sample was air-dried for soil particle size distribution, pH and enzyme activities, and the air-dried subsamples were finely ground to pass through 0.25 mm sieve for chemical analysis. The remaining fresh samples were sealed in plastic bags and stored at 4°C for basal soil respiration measurements.

Soil analysis

Soil particle size distribution was determined by the pipette method in a sedimentation cylinder, using sodium hexamethaphosphate as the dispersing agent

(Day, 1965). Macro-aggregates (>0.25 mm) were measured through routine dry- and wet-sieving (ISSCAS, 1978). Gravimetric water-holding capacity (WHC) was measured by the tube method (Wani *et al*., 1994). Soil pH was determined in 1:1 soil-water slurry with a combination pH electrode (Multiline F/SET-3, Germany). Soil organic C was measured by the dichromate oxidation method of Walkey and Black (Nelson and Sommers, 1982), total nitrogen by the Kjeldahl procedure (UDK140 Automatic Steam Distilling Unit, Automatic Titroline 96, Italy) (ISSCAS, 1978) and total phosphorus by UV-1601 spectrophotometer (Japan), after H_2SO_4-$HClO_4$ digestion (ISSCAS, 1978). Soil available N was determined by the alkalisable diffusion method, and available P by the Bray method (ISSCAS, 1978).

Basal soil respiration (BSR) was estimated through CO_2 evolution at 28°C in samples incubated for seven days (Alef, 1995). Measurements were made in the laboratory under standardized soil moisture condition at 60% of field capacity. Enzyme activities were assayed on air-dried sieved soil. Assays were performed to determine the activity of catalase (CA) (ml 0.1 N $KMnO_4$ g^{-1} ds 20 min^{-1}) (Johnson and Temple, 1964), urease (UR) (μ g NH_4+-N g^{-1} ds h^{-1}) (Tabatabai and Bremner, 1972), and neutral and alkaline phosphatase (UP, AP) (μ g Phenol g^{-1} ds h^{-1}) (Zhou and Zhang, 1980).

Data analysis

One-way analysis of variance (ANOVA) was carried out to detect the effects of land use and management systems on soil physical, chemical and biological properties. In cases where the F-test showed significant treatment differences, the least significant differences (LSDs) were performed to determine the differences between treatment means at $P<0.05$. Pearson correlation analysis was used to evaluate relationship among the selected properties.

Results and Discussion

Soil physical properties

Cultivation of natural grassland and subsequent tillage practices resulted in significant changes in soil structure, aggregate, and water-holding capacity (WHC) (Table 1). Characteristics of soil particle size fractions showed that the MC and AC soils averaged significantly lower silt content and slightly lower clay fraction in the plough depth of 0 to 15 cm than in the adjoining NG soil at the same soil depth. This indicated that adoption of these land use and management practices led to the loss of fine particles in the surface layers, largely due to accelerated wind erosion induced by tillage practices. Significant change in silt content and slight change in clay content during the 15 years of tillage suggested that wind erosion in this region sorted the soil material, removing especially the silt and very fine sand, and to a lesser extent clay. This result was in accordance with the findings of other authors in the erosion-prone regions of north China (Li *et al*., 2001; Hasi, 1996), who found that silt and very fine sand are the dominant components in the dust blown by wind erosion. The result also agrees with the findings of Lobe *et al*. (2001) from sandy soils of South African Highveld, who suggested that accelerated wind erosion induced by cultivation resulted in the removal of silt and to a lesser extent clay and fine sand. Furthermore, insignificant or slight difference in the particle size fractions was observed between NG soil and HO soil. The conversion of natural grassland to forest and subsequent regeneration of vegetation under tree canopy protected effectively the surface soil from wind erosion. Therefore, degradation in soil structure can be minimized under this system.

Though sandy soils have poor aggregation, there was significant difference among different land use and management systems. The natural grassland soil passed higher percentage of dry-aggregation and some water-stable aggregation. Fifteen years of cultivation considerably decreased aggregation. Among the three cultivated systems, HO with less soil disturbance had significantly higher dry aggregate than the tilled AC and MC systems, suggesting that use patterns, tillage methods, and cropping systems apparently influenced soil aggregation, with the effect of tillage method generally being the greatest (Unger, 1997).

Bulk densities were not significantly different among the treatments. The livestock grazing in NG increased bulk density, although the soil was protected by sod. However, the soils of plough depth in the tilled systems (AC and MC) were lessened by long-term tillage practices, despite the fact that greater residual sand content probably resulted in poorer aggregation and high bulk density (Islam *et al*., 2000). Compared to the natural grassland soil, WHC was lower in the tilled soils (AC and MC), but the untilled orchard soil had about the same WHC as NG soil. WHC was related to soil particle size distribution and macro-aggregation.

Soil chemical properties

Characteristics of individual chemical properties varied appreciably among the land use and management systems. The lowest pH value was noted in NG soil, showing a significantly less alkalinity than in soils under the cultivated systems (Table 1). One possible explanation is that soil in the natural grassland had significantly higher organic matter resulting from greater underground biomass and litter fall production over the surface layer (Fisher, 1995; Kaur *et al*., 2000), thus leading to more release of H^+ ions because of decomposition of organic matter into organic acids and CO_2 through root and soil respiration (Tornquist *et al*., 1999).

Despite no input of fertilizers, the natural grassland soil had more organic C and total N than did the cultivated soils (Table 1). Cultivation of grassland for up to15 years resulted in a 26 to 42% and 15 to 29% decline in soil organic C and total N, respectively. The rate of decline varied with the different soil and crop management systems. The most severe decline was observed in the MC site. The C:N ratios were wider under natural grassland than under cultivated lands, indicating slightly greater decline in C than N upon cultivation. Also, it resulted from N input from chemical fertilizer during cultivation. This decline in organic C and N was consistent with the results from several studies (Xiao *et al*., 1998; Lobe *et al*., 2001; Wang *et al*., 1998; Chan *et al*., 1995; Bowman *et al*., 1990). For example, in a study in the Bashang steppe of north China that has seriously desertified areas, Xiao *et al.* (1998) found that 8 years of cultivation in a native rangeland caused 55 to 68% reduction in organic C and 37 to 55% in total N in the top 20 cm soil layer. On the Vertisol plains of NSW, Australia, Chan *et al.* (1995) observed on an average 32% loss in SOC content in the cropped soils over a 2- to 50-year period. In the meadow steppe of Xilinguole, inner Mongolia, China, 23-year cultivation resulted in 34 to 38% loss in SOC content in the 0 to 35 cm depth (Wang *et al.*, 1998).

The lower levels of organic C and total N in cultivated soils might have resulted from a combination of lower C inputs because of less biomass C return on harvested land and greater C losses because of aggregate disruption, increased aeration by tillage, and accelerated wind erosion (Islam *et al.*, 2000; Lal, 1997). In our study area, the change in management from a grass cover to a more disturbed conventional tillage system might have accelerated wind erosion, thereby depleting organic C and N of soil. Significant relationship ($r = 0.71$ for C, $p < 0.005$; $r = 0.62$ for N, $p < 0.005$) between silt content and organic C and N further supported the postulation that the loss of organic C and N in the grassland-reclaimed cropland was mostly due to preferential removal by wind of the fine fractions that are enriched with organic matter and nutrients (Christensen, 1992; Lobe *et al.*, 2001).

Unlike organic C and total N, total P in the grassland was significantly lower than in the cultivated lands (Table 1). This can be attributed to the greater P input from P fertilization in the cultivated land, as some studies suggested that rebuilding of P pool in the soils depends mainly on supplementary supply of phosphorus fertilizers (Campbell and Janzen, 1995). The available P in NG soil was lower than in the HO soil and was same as in MC and AC soils. Total P was low, but relatively high content of available P in NG soil may be attributed to its higher organic matter and lower pH, which might have promoted the activity of P.

Soil biological properties

Significant difference in basic soil CO_2 respiration rate (BSR) was found among the treatments, the values being higher in the natural grassland and the lowest in the tilled systems (MA and AC) (Table 1). A high positive relationship ($r = 0.81$, $p < 0.0001$) was observed between BSR and organic C.

BSR can be viewed as an index of decomposer performance for microbial degradation (Jacinthe *et al.*, 2001). Saviozzi *et al.* (2001) suggested that BSR reflected the overall activity of microbial pool. Our results indicated that the cultivation of sandy grassland not only reduced soil organic C, but also accelerated microbial degradation. During the short-term incubation, the soil in AC site lost approximately 2.5% organic C, which was higher than the loss in NG soil (2.1% of the organic C). This suggested that accelerated wind erosion, increased aeration by tillage, and removal of crop residue and other biomass due to cultivation of natural grassland accentuated the loss of organic C by mineralization (Lal, 2000).

Individual enzyme activity assayed varied among land use and management systems. Catalase and urease activities were higher in the natural grassland than in the

Table 1. Selected physical, chemical and biological properties of soils under different land use systems

	Land use				LSD 0.05
	NG	HO	AC	MC	
Physical properties					
Bulk density (g cm^{-3})	1.38 (0.03)	1.41 (0.04)	1.42 (0.08)	1.40 (0.07)	NS
Particle size distribution					
Sand (%)	67.6 (1.8)c	70.7 (1.3)b	72.3 (2.2)b	76.0 (1.8)c	2.42
Silt (%)	24.8 (1.8)a	22.3 (1.3)ab	21.2 (3.4)bc	18.6 (2.6)c	3.24
Clay (%)	7.6 (1.1)	7.0 (1.3)	6.5 (1.9)	5.4 (1.0)	NS
>0.25 mm macro-aggregate					
Dry-sieving (%)	66.9 (7.6)a	40.6 (6.8)b	20.0 (4.0)c	18.8 (3.4)c	7.66
Wet-sieving (%)	11.4 (3.2)	5.3 (4.9)	0	0	
PAD	83	87	100	100	
Water-holding capacity (%)	27.5 (1.7)a	26.8 (0.7)a	24.6 (0.9)b	23.3 (1.5)b	1.73
Chemical properties					
pH (H_2O) (1:1 soil/water)	7.22(0.06)	7.65 (0.08)a	7.73 (0.1)a	7.76 (0.06)a	0.09
Organic C (g kg^{-1})	10.59 (1.24)a	7.85 (0.70)b	7.14 (0.54)bc	6.15 (0.66)c	1.11
Total N (g kg^{-1})	0.95 (0.12)a	0.81 (0.11)b	0.73 (0.08)b	0.67 (0.12)b	0.14
C:N ratio	11.14 (0.55)a	9.78 (0.92)b	9.79 (0.77)b	9.29 (0.77)b	1.02
Total P (g kg^{-1})	0.37 (0.03)c	0.57 (0.02)a	0.53 (0.34)a	0.45 (0.04)b	4.35
Available N (mg kg^{-1})	68.0 (3.3)a	63.3 (2.5)b	60.2 (3.6)b	46.0 (3.5)c	4.35
Available P (mg kg^{-1})	13.0 (1.2)bc	19.6 (1.5)a	14.1 (2.5)b	11.4 (1.5)bc	2.31
Biological properties					
BSR (mg CO_2 g^{-1} 7 day)	0.82 (0.07)a	0.66 (0.05)b	0.58 (0.05)c	0.57 (0.06)c	21.5
CA (ml 0.1 NK Mn)4g^{-1}d*20min^{-1})	1.27 (0.08)	1.45 (0.07)	1.33 (0.18)	1.34 (0.12)	NS
UR (μ g NH_4^+-N g^{-1} ds h^{-1})	11.8 (1.9)c	27.2 (4.4)a	19.5 (2.2)b	17.4 (1.8)b	26.4
NP (μ g Phenol g^{-1} ds h^{-1})	17.7 (2.0)a	7.9 (0.5)b	6.1 (1.0)c	4.9 (1.2)c	1.74
AP (μ g Phenol g^{-1} ds h^{-1})	20.0 (2.6)a	15.7 (1.7)b	14.6 (0.7)bc	13.0 (1.0)c	15.9

PAD: Percentage of aggregate destruction; CA: catalase; UR: urease; NP: neutral phosphatase; AP: alkaline phosphatase, ds: dry soil.

Data are means (SD) of five replicates at each site. Means with different letter within a variable indicate significant difference at $P<0.05$.

three cultivated systems, but no significant difference was found in CA activity, whereas the neutral and alkaline phosphatase activities were higher in the cultivated systems than in the natural grassland. Among the three cultivated systems, enzyme activities assayed were significantly higher in the less disturbed system (HO) than in the tilled systems (AC and MC) (Table 1). Soil enzyme activities are influenced by a number factors such as soil structure, moisture, pH and agronomic practices, including fertilizers, amendments, vegetation cover and pesticides (Gianfreda and Bollag, 1996). The higher values of urease activity in cultivated systems as

African Highveld. *European Journal of Soil Science* 52: 93-101.

McCarty, E.W., Shogren, D.R. and Bremner, J.M. 1992. Regulation of urease production in soil by microbial assimilation of nitrogen. *Biology and Fertility of Soils* 12: 261-264.

Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis* (Eds. A.L. Page, R.H. Miller and D.R. Keeney), Part 2, pp. 539-577. 2nd Edition, Agronomy, Madison WI.

Riffaldi, R., Saviozzi, A., Levi-Minzi, R. and Cardelli, R. 2002. Biochemical properties of a Mediterranean soil as affected by long-term crop management systems. *Soil and Tillage Research* 67: 109-114.

Salam, A.K., Katayama, A. and Kumuira, M. 1998. Activities of some soil enzymes in different land use systems after deforestation in hilly areas of West Lampung, South Sumatra. *Indonesia Soil Science and Plant Nutrition* 44: 93-103.

Tabatabai, M.A. and Bremner, J.M. 1972. Assay of urease activity in soils. *Soil Biology and Biochemistry* 4: 479-487.

Tornquist, G.C., Hons, F.M. and Feagley, S.E. 1999. Agroforestry system effect on soil characteristics of the Sarapiqi region of Costa Rica. *Agriculture, Ecosystems and Environment* 73: 19-20.

Unger, P.W. 1997. Management induced aggregation and organic carbon concentration in the surface layer of a Torretic Paleustoll. *Soil and Tillage Research* 42: 185-208.

Wani, S.P., McGill, W.B. and Hauger-Kozyra, K.L. 1994. Improved soil quality and barley yields with faba beans manure, forages and crop rotation on Gray Luvisol. *Canadian Journal of Soil Science* 74: 75-84.

Wang, T. 2000. Land use and sandy desertification in north China. *Journal of Desert Research* 20: 103-108.

Wang, X.J. and Gong, Z.T. 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma* 81: 339-355.

Wang, X.F., Chen, Z.Z. and Tieszen, L.T. 1998. Distribution of soil organic carbon on the major grasslands of Xilinguole, Inner Mogngolia, China. *Acta Phytology Sinica* 22(6): 545-551 (in Chinese with English Abstract).

Xiao, H.L., Zhao, X. and Zhao, W.Z. 1998. Study on Uap-Ustic Isohumisol degradation under farming in Hebei, China. *Acta Pedology Sinica* 35(1): 129-134 (in Chinese with English abstract).

Xu, B., Liu, X.M. and Zhang, X.Y. 1993. Soil wind erosion of farmland and its control in central Naiman, Inner Mongolia. *Journal of Soil and Water Conversation* 2: 75-88 (in Chinese with English abstract).

Zhao, H.L., Zhao, X.Y. and Zhang, T.H. 2000. Causes, processes and countermeasures of desertification in the interlocked agro-pastoral areas of north China. *Journal of Desert Research* (suppl. 1), 22-28 (in Chinese with English Abstract).

Zhou, L.K. and Zhang, Z.M 1980. Analysis methods for soil enzyme activities. *Journal of Soil Science* 5: 37-38 (in Chinese with English Abstract).