Landscape Ecology **19:** 621–629, 2004.

Research article

Soil C and N Content Under Evolving Landscapes in an Arid Inland River Basin of Northwest China

Wang Genxu[1,2,*], Yao Jinzhong[2], Luo Lin[2] and Qian Ju[1]
[1]*MOE Laboratory of Western China's Environmental Systems, Lanzhou University, Lanzhou 730000;* [2]*Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000;* **Author for correspondence (e-mail: gxwang@ns.lzb.ac.cn)*

Received 27 March 2003; accepted in revised form 27 November 2003

Key words: Arid region, Landscape evolution, Soil organic C and N contents, Deposition and losses, Impacts

Abstract

The state of a landscape is primarily reflected by its soil nutrients and organic matter status, which in turn are related to the type, size and number of landscape elements or patches. Evolving landscape patterns inevitably cause an evolution in ecosystem functionality. In particular, in arid regions, gained, lost and existing soil N and C pools have important ecological implications. The impacts of evolving landscapes in the middle reaches of the Heihe River basin of northwest China on soil organic C and N losses were assessed by both quantitative and computer modelling methods. In the period 1987-1997, patch transitions of the region's evolving landscapes have been predominantly characterized by a farmland expansion of $1.5 \cdot 10^3$ km^2, and the desertification of 15.12% of existing farmlands into desert. As the result of such changes, alpine steppe and piedmont warm and desert steppe decreased by 43.9% and 2.72% respectively, whereas, plain swamp meadow and gobi and sandy desert increased by 13.2% and 10.77%, respectively. Consequently, soil organic matter and N contents decreased significantly in most landscape patches. In the study region, over these ten years, net soil organic C and N losses reached 5.30 Gg and 0.51 Gg, respectively, a pattern repeated over the entire arid inland region of northwest China, due to similar hydrological resources and patterns of regional development. Large soil C and N losses caused by landscape changes will inevitably result in significant new environmental problems.

Introduction

The arid zones of the inland dry-lands of northwest China (north of 35 N, west of 106 E), include the entire Xinjiang Autonomous Region, Hexi Corridor in Gansu Province and the area west of the Helan Mountains in Inner Mongolia Autonomous Region. They occupy 24.5% of China's total land area. Situated deep in the hinterland of Eurasia, it is one of the driest zones in the world (Shi 1995). Unlike many other arid zones in the world, the geomorphologic features of northwest China's dry lands exhibit an alternation of tall mountains (Altay, Tianshan, Qilian, and Kulun Mountains, amongst others) and intermountain depressions. Under this alternation, the 300-1000 mm yr^{-1} of precipitation originating in moist air masses intercepted by the mountains, generate centripetal stream/river systems, each watershed being relatively independent hydrological, biogeochemical and land use unit (Wang et al. 1999; Fan et al. 2001). Some 653 inland rivers arise from these mountains, amongst which the Tarim and Heihe are the two largest. Extensive exploitation of water resources over the past 50 years have made landuse and land cover changes the main mark of environmental changes in the region (Wang et al. 2002; Fan et al. 2001). While cultivation has long been the primary landuse in the region, with the economic development and population growth of the last 10 years, cultivation has been extended into the piedmont grassland zone at the upper alluvial fan, to the mountain meadow zone and the construction of man-made oases has extended upstream (Wang et al. 2002; Fan et al. 2001). In the meantime, large areas of cultivated plains lands distant from the river channel have been abandoned due to lack of irrigation water, thereby altering land use patterns (Wang et al. 2002). Heavy water resource utilization and land use changes have resulted in marked evolution of landscapes.

Landscape ecology is largely founded on the premise that the pattern of landscape elements (patches) strongly influences ecological processes. Landscape heterogeneity is one of the central ideas of landscape ecology, underpinned by the close relationship of landscape spatial patterns and functional flows (Forman 1995; Ritters and O'Neill 1995). Different landscape patterns or changes thereto result in a functional evolution of the landscape (Farina 1998; Xiao et al. 1997). For those reasons, the ability to quantify landscape structure is a prerequisite to the study of landscape function and change. But the quantitative relationships between landscape patterns and ecological processes, landscape structure and ecological functions are relatively poorly known (Vincent et al. 2000; Xiao et al. 1998). Landscape evolution includes occurrence, maintenance and disappearance of patches (Pickett et al. 1995; Xiao et al. 1998). Hence, evolving landscape patterns will inevitably cause an evolution in the function of ecological systems. In this paper, the Heihe River watershed, the second largest arid inland watershed of northwest China, served as the case study region. Within the context of this evolving landscape attempts were made to document systematically the changes in soil nutrients and soil C and N losses occurring under conditions of landscape spatial pattern variation.

Study Area and Landscape Types

The Heihe River basin, the second largest inland river basin in the arid region of northwest China, is located between 96 42' E − 102 00' E. The middle reaches of the Heihe River watershed, where the study was undertaken, were located in the central portion of the Hexi Corridor, Gansu province, including the counties of Minle, Shandan, Linze and Goatai, and Zhangye city,. The middle reaches of the Heihe River watershed, totalling 4.08· 10^4 km^2 in area (Figure1), receive between 250 mm yr^{-1} in the mountainous areas of the south, to less than 100 mm yr^{-1} in the northern high plains area. Under the influences of landforms, climate and vegetation, zonal soils are formed from the south (Qilian Mountain) to the north plain area: black soil, mountain chestnut soil, sierozem, grey desert soil, grey brown desert soil and blown sand soil, in addition to zonal soil types including meadow soil and aquisoils occurring in the Zhangye and Linze regions. Land types in the study area can be divided into: mountain meadow grassland, piedmont desert steppe grassland, agricultural land (includes cropland, forested land and garden land), plain swamp meadow grassland (including tree and shrub grasslands), and gobi and desert sandy land (Chen and Li 2000).

According to land types and interpretation of satellite and remote sensing images, the land in the study area was divided into nine landscape-ecotypes: (i) alpine steppe (AL steppe), (ii) middle-mountain meadow (MM meadow), (iii) piedmont warm and desert steppe (PD steppe), (iv) farmland, (v) planted forest (PL forest), (vi) plain swamp meadow (PS meadow) (vii) gobi and sandy desert (GS desert), (viii) Water areas (WT areas), and (ix) residential areas (RS areas). The classification system of landscape patch types and identification procedures were described by Lu et al. (2002). Landscape characteristics in the study region is presented in Table 1. In the middle reaches of the Heihe River basin, the four main landscape types: PD steppe, farmland, GS desert and PS meadow, accounted individually for 38, 33, 15, and 10%, respectively, or a combined 96% of the study area. The predominant PD steppe ecotype showed the greatest mean single patch size of all landscapes (232.4 km^2 $patch^{-1}$), and the lowest patch number (28) among the top four landscape types (Table 1). The number of farmland and GS desert patches (96 and 34, respectively) were the greatest and third greatest among all landscapes and their mean single patch sizes 75% and 67% smaller than that of the PD steppe, indicating a more fragmentary distribution. PS meadows, a landscape seldom surviving the intensive farmland development of the middle reaches of Heihe watershed, had a mean single patch size less than a tenth of that of the PD steppe. Many of the PS meadow patches were situated next to farmland and showed a more fragmentary distribution than any of the four most common landscapes.

Table 1. Landscape types and distributing features

Landscape	Area and characteristics			
	Area (km^2)	Percent of total land area	No. patches	Area per patch (km^2)
PD steppe	6506.76	37.97	28	232.4
Farmland	5655.43	33.03	96	58.9
GS desert	2579.31	15.06	34	75.9
PS meadow	1685.12	9.84	84	20.1
AL steppe	431.12	2.52	9	47.9
PL forest	94.18	0.55	4	23.5
Wetland	81.31	0.47	9	9.0
Residential	78.43	0.46	9	8.7
MM meadow	15.87	0.09	2	7.9

Methodology and Data Acquisition

Evolving landscapes analysis

Analysis of evolving landscape over the last 10 years using the FRAGSTATS model (McGarigal and others, 1994), employed two sets of remote sensing data (1987, 1997). Using the Crosstab module in the GIS software IDRISI to calculate both the transition matrix and the cross-classification map. 10-year interval landscape patch transfer probability matrices were established using the remote sensing data, in which matrix elements represented the percentage area transferred from one landscape type to another. The %LAND index can be used to indicate the processes of landscape change (Lu et al. 2001; McGarigal et al. 1994).

Soil sampling and data analysis

Based on the landscape types found to be evolving at the greatest rate, four sampling plots were selected in lands of each of seven different landscape types: MM meadow and AL steppe in the south piedmont of the Qilian Mountain; PD steppe, Farmland and PL forest in the upper and middle portions of the piedmont alluvial fan; PS meadow in wetland area and GS desert in desertification area (including gobi and sand land). Various counties' land use statistics served to quantify, for each sampling plot, the temporal and spatial distribution of cultivated lands transformed from grassland and forest land, existing abandoned cultivated lands, and grasslands transformed from abandoned cultivated lands. The sampling sites within each plot were chosen based on different landscape types and the timing of landscape changes (for example, the time of cultivated lands transformed from grassland was divided into 3-5years and 10 years and over). 2-3 replicated soil samples were taken from each sampling site. Based on the soil layer depth believed to be affected by landscape changes, soil samples were collected from 0-1.5 m, in four intervals: 0-0.3, 0.3-0.5, 0.5-1.0 and 1.0-1.5 m. All soil samples were analyzed for bulk density, organic matter and total and available soil nutrient (N, P and K) contents and mean values calculated for each site. The test methods used in this paper were: SOM, the Walkey-Black chromic acid digestion method, total P, molybdenum antimony colorimetry method, total N, salicylate-hypochlorite Kjeldahl digestion method (Nanjing Agricultural University, 1992).

Estimating changes in soil C, N and P change

Based on the soil layer depth affected by landscape changes, the 0-1.5 m soil profile was considered to best represent N and P changes. The rate of change in soil nutrients ($\Delta Y_{i\,,}$ kg) was calculated as (Guo et al. 2001; Jin et al. 2001):

$$\triangle \mathrm{Y_i} = \sum_{j=1}^{n} \left(\rho_i Y_i - \rho_j Y_j\right) HF_i a_{ij} \tag{1}$$

Where:

Y_i, Y_j=are the soil nutrient contents of landscapes i and j, respectively, g kg^{-1} (soil)

ρ_i , ρ_j=are the bulk densities of soils of landscapes i and j, respectively, Mg (soil) m^{-3}

H=is the mean soil profile depth (1.5 m)

F_i=is the area of landscapes i (m^2), and

a_{ij}=is the transfer probability element of the different periods.

Landscape changes can significantly affect the soil organic carbon pool. Soil organic carbon content per

Table 2. The transition matrix of landscape types in the middle reaches of the Heihe River watershed from 1987 to 1997

	1997 (j)								
1987 (i)	PD steppe	Farmland	GS desert	PS meadow	AL steppe	PL forest	Wetland	Residential	MM meadow
PD steppe	70.0	9.6	17.4	2.3	0.3	0.1	0.1	0.0	0.2
Farmland	13.0	76.8	2.1	4.1	1.8	0.9	0.5	0.9	0.0
GS desert	16.2	6.5	56.5	18.5	0.0	0.0	0.1	1.6	0.0
PS meadow	6.8	16.8	20.2	50.1	0.04	1.6	4.1	0.5	0.0
AL steppe	23.8	49.8	0.0	0.0	25.5	00.0	0.1	0.2	0.0
PL forest	2.5	51.7	6.6	24.1	0.0	12.6	0.5	2.1	0.0
Wetland	5.2	34.0	8.8	33.6	0.0	0.0	18.4	0.0	0.0

unit area was calculated as (Duan et al., 1997; Fang et al., 1996):

$$P_c = A\rho Hba \quad (2)$$

Where:

P_c=is total soil organic carbon pool in the parcel of land undergoing transition (Mg C)

A=is the surface area of the parcel of land undergoing transition (m^2)

b=is the mean organic matter content in soil (g kg^{-1}), and

a=is the unitless Bemmelen Index of 0.58, used to convert organic matter content to organic carbon content.

Carbon emissions from the soil arise mainly from two processes: (i) soil respiration, including plant root respiration in soil, microorganismal decomposition and mycorrhizal respiration, and (ii) carbon released to the atmosphere as a result of organic matter decomposition due to shifts in landuse. Carbon deposition/emission fluxes resulting from landscape changes were calculated as:

$$E_c = P_{c1997} - P_{c1987} \quad (3)$$

where:

E_c=is the carbon deposited (+ values) or emitted (- values) due to landscape changes (Mg C)

P_{c1997} , P_{c1987}=are total soil organic carbon pool in the parcel of land undergoing transition, before (1987) and after (1997) the said transition (Mg C)

Deposition or loss of N was calculated in a similar manner.

Results and analysis

Landscape-type transitions and landscape pattern changes

Landscape patch transfer probability matrices were developed to allow a comprehensive analysis of the magnitude and the direction of patch changes (Table 2), each element representing the transition ratio from the i th patch type in 1987 to the j th patch type in 1997.

The PD steppe and farmland were not only the predominant types but also those exhibiting the least transition to other types. From 1987 to 1997, 17.4% of original PD steppe turned to GS desert and 9.6% turned to farmland, the remaining 70% was unchanged. For farmland, 76.8 remained unchanged, with 13.02% turning into PD steppe and 4.1% turning into PS meadow. Other patch types changed more significantly: for example, only 25.5, 12.6, 18.4, 50.0, 56.5% respectively, of original AL steppe, PF forest, WL area, PS meadow and GS desert remained unchanged. Some 49.8, 51.7 and 16.8% of AL steppe, PL forest and PS meadow, respectively, turned into farmland. In the study area, there is a long transitional zone between desert (including PD steppe and GS desert patch type) and farmland, where desert transformed to farmland and farmland transformed to desert co-exist. In this zone, a total of 67576.8 ha farmland turned to desert and 79344.9 ha of desert turned into farmland. Compared with the agricultural development of deserts, that of oasis was much less prevalent. The ebb and flow of opposing processes in landscape patch transition also occurred for other landscape changes: PS meadow to/from GS desert, and PD steppe to/from GS desert.

In the study region, transitions from AL steppe were quite significant. In 1987, some 75033 ha of

Table 3. Comparison of area of different landscape types in middle reaches of Heihe River watershed basin in 1987 and 1997

Landscape	Landscape dimensions			
	Area (km^2)		Percent of total area	
	1987	1997	1987	1997
PD steppe	6688.6	6506.8	42.0	38.0
Farmland	4505.1	5655.4	28.3	33.0
GS desert	2328.4	2579.3	13.6	15.1
PS meadow	1488.4	1685.1	9.3	9.8
AL steppe	768.5	431.1	4.8	2.5
PL forest	98.1	94.2	0.6	0.6
Residential	65.4	78.4	0.5	0.5
MM meadow	17.5	15.9	0.1	0.1

high-coverage steppe lands were present along the edge of the Qilian Mountains and in the south-eastern portion of the study region. By 1997, 49.8% had been turned into farmland, and another 23.8% had turned to desert. Other significant changes were that 18.5% of GS desert, 33.6% of WL areas and 24.1% of PL forests turned into PS meadow. These complex landscape patch changes resulted in wide variations in individual landscape type areas. As showed in Table 3, The area of AL steppe, MM meadow, PD steppe and PL forest declined over the period 1987-1997. Meanwhile, the areas of farmland, PS meadow and GS desert increased. These changes had important impacts on soil N and C pools and on N and C deposition.

Impacts of landscape type changes on soil organic matter and N content

In the past 10 years the main landscape patch changes in the study region were a result of various grasslands in the piedmont and plains area (including AL steppe, PS meadow and PD steppe) being reclaimed into farmland and part of cultivated lands in the plains area being abandoned and turning into PD steppe due to water shortages. Transition from PS meadow and PD steppe landscape types to GS desert was also very serious (Table 2).

Common to the south and north piedmont zones of the study region, the PD steppe landscape, dominated by gray and gray brown desert soils, has served as the main zone of agricultural expansion over the last 10 years. Organic matter content in the primary soil varied between 6.9-14.35 g kg^{-1} and total N content between 0.45-0.88 g kg^{-1}. After 2-3 years of cultivation, significant decreases in organic matter and total N contents occurred in these soil types. On average, organic matter content decreased by 26.97% and total N content by 22.95%. But after ten years of cultivation, soil organic matter and total N content in the 0-1.5 m soil profile showed a clear increase over pre-cultivation soil (Figure 2).

Compared to the widely distributed PD steppe soils, PS meadow soils (include salinized meadow and swamp meadow soils) had a higher pre-cultivation organic matter and total N content. After 10 years of cultivation the nutrient content of former PS meadow soils remained below those of 3-5-year cultivated soils, showing that cultivation resulted in a continuous decrease in soil nutrients, of which organic matter on an average decreased by 29.9% and total N by 29.5% (Figure 3).

In the study region, over the last 10 years (the period 1987-1997), no transformation of cultivated land to PD steppe has occurred by design; however, large areas of cultivated lands have undergone such a transition as they were abandoned due to lack of irrigation water and other economic consideration. Such unplanned changes have had serious impacts on the soil nutrient contents of typical abandoned and adjacent maintained agricultural lands. Some 2-3 years after abandonment, organic matter in the soil profile decreased significantly, on average 33.8% in the cultivated layer (0-0.2 m), and 25.4% and in 0-1.5 m soil profile. After 10 years of abandonment organic matter content in the cultivated layer showed no change relative to 3-5 year levels, but that in the 0.2-1.0 m soil profile had decreased significantly. After 15-20 years of abandonment the organic matter content in the cultivated layer had decreased relative to 10 years levels, whereas that of the 1.0-1.5m soil profile showed no evident changes relative to 10 years levels (Figure 4A). Total N content in soil decreased continuously with lengthening duration of abandonment (Figure 4B). On average, the total N content in the 0-1.5 m soil profile decreased by 10.8, 24.2 and 29.5%, respectively, after 2-3, 10 or 15-20 years.

Impacts of landscape transition on soil N, C deposition and emission

Under the facts that the additional cultivated area per year was approximately same over the period 1987-1997 in the middle reaches of the Heihe River basin (Wang et al. 2002; Lu et al. 2001). Assuming that the expansion rate of cultivated land was uniform over the period 1987-1997, i.e., one-half of cultivated land

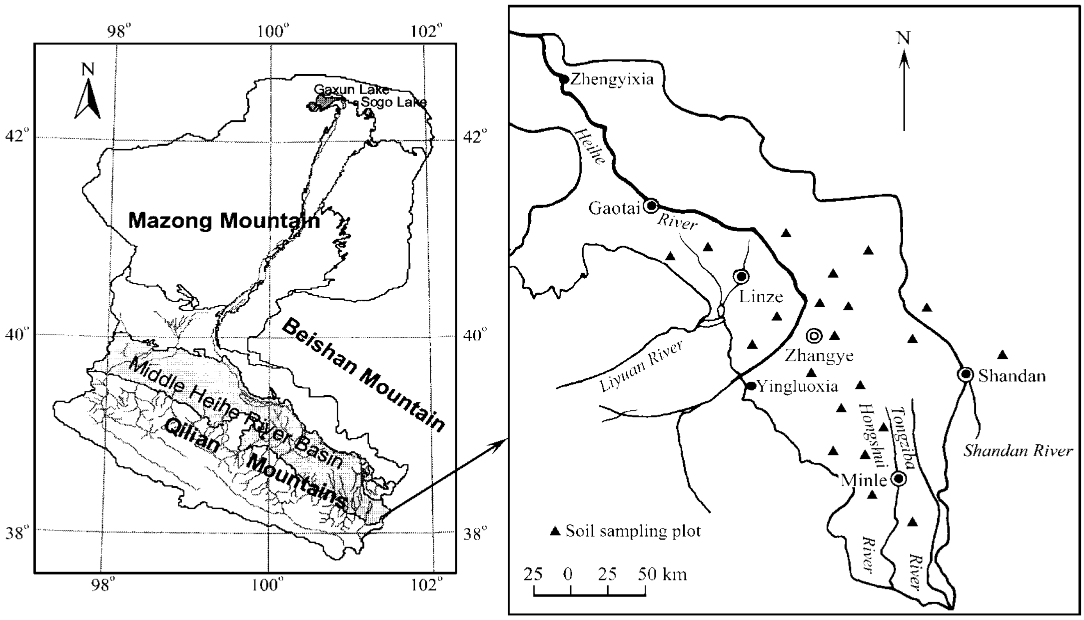

Figure 1. The sketch map of study area.

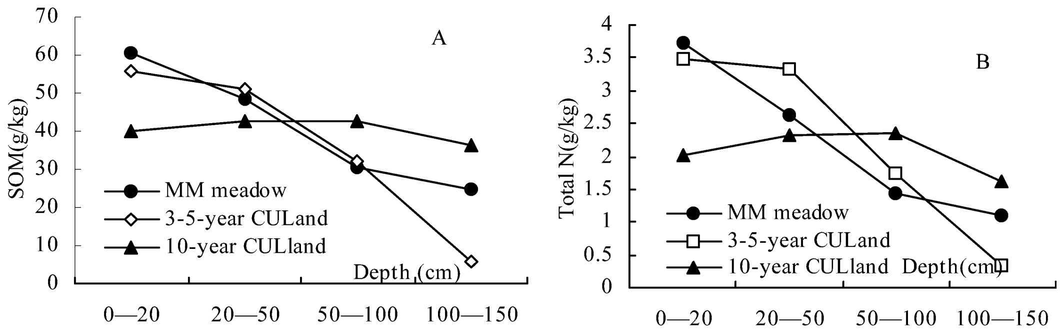

Figure 2. Change in organic matter (a) and total N (b) contents in ALP steppe soil under cultivation condition

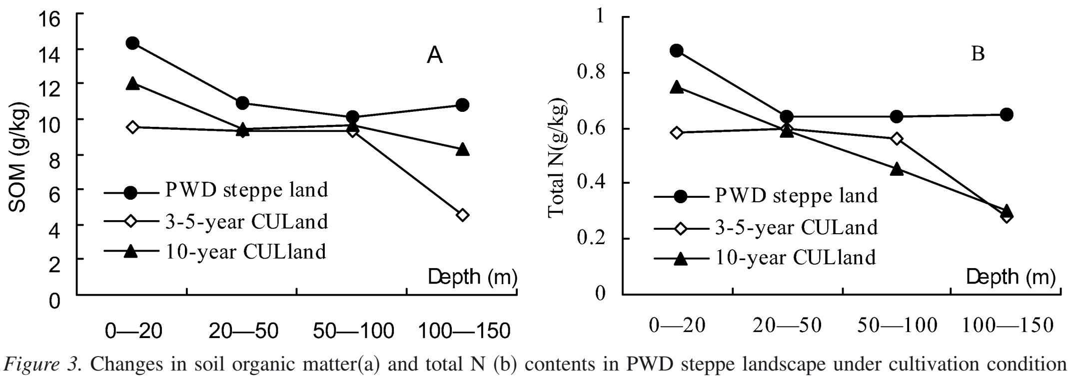

Figure 3. Changes in soil organic matter(a) and total N (b) contents in PWD steppe landscape under cultivation condition

was reclaimed between 1987 and 1992 and the other half between 1993 and 1997, the losses of N and organic matter in cultivated land can be calculated on a 5- or 10-year basis. Given the particularly complex

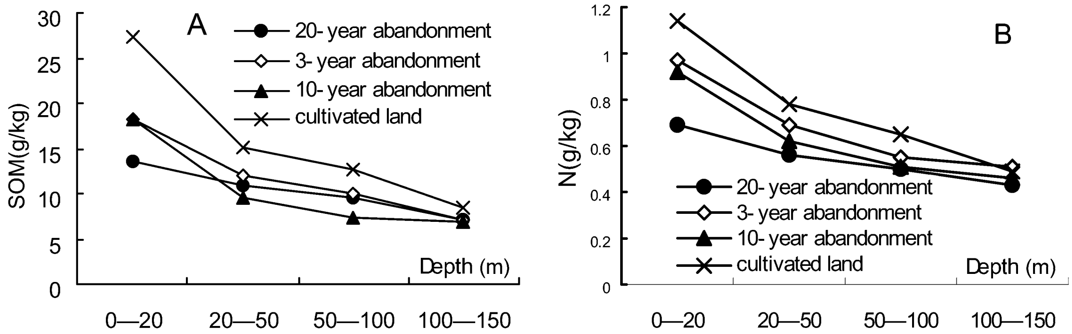

Figure 4. Soil organic matter and total N content changes after cultivated land turned into desert grassland

Table 4. Landscape soil N gain (+) or loss (-) caused by transition of landscape patches in middle Heihe River basin (Gg N)

	1997 (j)							
1987 (i)	PD steppe	Farmland	GS desert	PS meadow	AL steppe	PL forest	Residential	MM meadow
PD steppe	0.0	− 109.6	− 290.3	+76.7	+8.2	+0.98	0.0	0.0
Farmland	− 134.0	0.0	− 57.1	+60.3	+17.0	− 5.2	− 9.3	0.0
GS desert	+123.8	+96.8	0.0	+424.3	0.0	0.0	0.0	0.0
PS meadow	− 50.1	− 74.9	− 223.1	0.0	0.0	− 8.8	− 3.8	0.0
AL steppe	− 39.8	− 35.0	0.0	0.0	0.0	0.0	− 0.3	+7.9
PL forest	− 0.3	+5.1	− 2.4	+8.4	0.0	0.0	− 2.6	0.0

Table 5. Landscape soil C gain (+) or loss (-) caused by transition of landscape patches in middle Heihe River basin (Gg C).

	1997 (j)							
1987 (i)	PD steppe	Farmland	GS desert	PS meadow	AL steppe	PL forest	Residential	MM meadow
PD steppe	0.0	− 1060.8	− 3349.3	+1130.7	+66.3	+3.92	0.0	0.0
Farmland	− 3830.8	0.0	− 604.4	+1171.4	+103.9	− 83.49	− 264.8	0.0
GS desert	+1429.1	+1023.9	0.0	+5819.9	0.0	0.0	0.0	0.0
PS meadow	− 741.4	− 1529.5	− 3060.5	0.0	0.0	− 162.6	− 55.6	0.0
AL steppe	− 322.8	− 213.3	0.0	0.0	0.0	0.0	− 2.71	+7.9
PL forest	− 1.4	+82.0	− 21.6	+155.1	0.0	0.0	− 11.7	0.0

and poorly studied gains and losses of soil N and C during the transition from wetlands to other landscape types, such transitions were not considered in this study. The soil N and C gains or losses during transitions from AL steppe, PS meadow, farmland or PL forest to residential area were estimated as for PD steppe. The N and organic C gains or losses resulting from landscape transitions in the period 1987-1997 were calculated according to Equation (1) and (3), and are presented in Table 4, Table 5, respectively.

Some transitions, such as AL steppe to MM meadow, farmland to AL steppe and all plain landscape types turning to PS meadow, resulted in gains in soil N. Particularly in the case of the transition from GS desert to farmland, PS meadow or PD steppe, the process was one of ecological rehabilitation, the soil N would be deposited 96.77 Gg, 123.85 Gg and 424.3 Gg, respectively (Table 4). The majority of remaining transition pairings resulted in soil N loss, such as all grasslands turned to farmland, farmland abandoned and turned into PD steppe and all landscape types turned to GS desert. In the region, over the period 1987-1997, soil N loss due to grassland (AL steppe, PS meadow and PD steppe) cultivation in the region was, on average, 419.3 Gg, or 6.25 Mg ha^{-1} yr^{-1}, of which 2.57 Mg ha^{-1} yr^{-1} was contributed by the PD steppe to cultivated land transition. Soil N loss under the PS meadow to cultivated land transition was 17.9 Gg or 4.12 Mg ha^{-1} yr^{-1}. Over the same 10 year period, about 147.84 km^2 of cultivated land was abandoned and turned into PD steppe, resulting in a total soil N loss of 40.87 Gg, or 2.76 Mg ha^{-1} yr^{-1}, a higher rate than observed for the PD steppe to cultivated land transition over the same period. In the middle reaches of Heihe River watershed, the largest soil N losses occurred under landscape transitions of farmland to PD steppe, PD steppe to GS desert, and PS meadow to GS desert: 134.01 Gg, 290.26 Gg and 223.12 Gg, respectively (Table 4).

The estimated organic carbon losses values presented in Table 5 only consider changes occurring under landscape patch transition and not those attributable to root respiration in soil, microorganismal decomposition and mycorrhizal respiration. Similarly soil N gains were those resulting from landscape patch transitions. Soil organic C gains occurred in the landscape transitions of AL steppe to MM meadow, farmland to AL steppe and of all plain landscape types (PD steppe, farmland, GS desert and PL forest) to PS meadow. Among these, those of farmland, PD steppe and GS desert to PS meadow resulted in important gains in soil organic C: 1.17 Tg, 1.13 Tg and 5.82 Tg, respectively. Conversely, most landscape patch transitions resulted in soil organic C losses. The transition of MM meadow and PD steppe into cultivated land resulted in mean organic carbon losses of 5.38 kg C m^{-2} and 0.97 kg C m^{-2}, respectively. The transition of farmland into PD steppe resulted in a mean organic carbon loss of 3.73 kg C m^2. In the middle reaches of the Heihe River watershed, some major landscape patch transitions, such as farmland to PD steppe, PS meadow to farmland, and PD steppe to farmland resulted in soil organic C losses of 3.83 Tg, 1.53 Tg and 1.06 Tg, respectively. The transition of farmland, PS meadow and PD steppe to GS desert resulted in soil organic C losses of 0.60 Tg, 3.06 Tg and 3.35 Tg, respectively (Table 5).

On the scale of the entire study region, the whole soil N, C losses and gains were estimated for each initial landscape (Table 6). In the period 1987-1997, due to the complex transitions of landscape patches including AL steppe, MM meadow, PD steppe, PS meadow, farmland, etc. an overall net loss of soil C and N occurred: 13.78 Gg of soil organic C and 1.16 Gg of soil N were lost. The biggest changes occurred in the GS desert landscape type, where over the period 1987-1997, the transition of GS desert patches to other landscape types resulted in large gains in the soil organic C and soil N pools: 8.27 Gg and 0.64 Gg, respectively (Table 6). In the same period, over the entire middle reaches of the Heihe River watershed, the net losses in soil organic C and N were 5.30 Gg and 0.51 Gg, respectively.

Table 6. Soil N and organic C losses caused by landscape changes occurring in the middle reaches of the Heihe River watershed over the period 1987-1997, by landscape types (Gg).

Landscape type	Soil N losses (Gg)	Soil organic C losses (Gg)
PD steppe	314	3209
Farmland	128	3508
GS desert	− 645	− 8273
PS meadow	361	5549
AL steppe	67	473
PL forest	− 8	− 202
MM meadow	290	1037
Total	506	5302

Conclusions

Between 1987 and 1997 the landscape in the middle reaches of the Heihe River have tended to become fragmented and diversified. The evolution of the landscape in the region has been mainly characterized by two processes: farmland expansion and landscape desertification. Nearly all landscape patch types in the region have had some portion turned into farmland. Indeed some $1.5 \cdot 10^3$ km^2 of new farmland was reclaimed from other landscape types, of which $1.1 \cdot 10^3$ km^2 were irrigated. Meanwhile, the landscape patch desertification also occurred for all landscape types, leading to an increase in desertified areas of $1.1 \cdot 10^3$ km^2, of which $0.7 \cdot 10^3$ km^2 came from farmland, primarily as a result of insufficient water resources in the region (Lu et al., 2003). The phenomenon of landscape transition was not only dominant in the middle reaches of the Heihe River watershed, but also in the entire arid inland region of northwest China, due to similar water resources limitations and modes of regional development (Wang et al. 1999).

Evolving landscape patterns will inevitably cause an evolution in the function of ecological systems. Processes involved in C and N pool gains and losses were strongly tied to landscape changes. In the arid inland region studied, namely the middle reaches of the Heihe River watershed in northwest China, the soil organic matter contents of AL steppe and PD steppe, the two most widely distributed landscape patches, decreased by 1.86% and 27.2%, respectively, while soil N contents decreased by 27.69% and 22.95%, respectively, as a result of their transition to farmland. The transition of PS meadow to farmland resulted in 52.97% and 35.44% declines in soil organic matter and N contents, respectively, over a 10 years period. Meanwhile, farmland desertification resulted in declines of soil organic matter and soil N content of 25.4% and 10.7% during first 3 years after abandonment. These landscape patch transitions and soil N, organic matter changes led to important changes in regional soil N and organic C gains and losses. Between 1987 and 1997, the net regional soil organic C and N losses reached 5.30 Gg and 0.51 Gg, respectively. Owing to the special mountain-basin alternating landforms of the inland basin, there exist a series of relatively independent yet geographically close hydrological and biogeochemical cycles occurring in arid northwest China. The large losses of soil C and N will inevitably cause serious environmental problems.

Acknowledgements

This study was funded by the Key Innovation Project of the Chinese Academy of Science (No. KZCX1-10-06 and No. KZCX1-09-04) and the Natural Science Foundation of China (No. 40171002).

References

Longheng C. and Fuxin L. 2000. The soil in Hexi Corridor of China. Chinese Environmental Science Press, Beijing, China.

Zili F., Yingjie M., Fang J., Ranghui W. 2001. Water resource use, oasis evolution and ecological balance in Tarim Basin. Journal of Natural Resources 16: 22–27.

Jingyun F., Guohua L., Sunling X, 1996a. Carbon pool of terrestrial ecosystem in China. In: (Wang Gencheng, Wen Yupu, eds.), Monitoring of greenhouse gas concentration and emission and relevant processes, China Environmental Science Press, 95-101.

Farina A. 1998. Principles and Methods in Landscape Ecology. Chapman and Hall Press, London, UK

Forman R.T.T. 1995. Some general principles of landscape and regional ecology. Landscape Ecology 10: 133–142.

Bojie F., liding C., Chansheng H. 1999. Integrating landscape ecological principles and land evaluation for sustainable land use. Journal of Environmental Sciences 11: 136–140.

Li X. 2000. Viewed the ecological developmental hot point and preface from the 15th Annual Meeting of American Landscape Ecology. Acta Ecologica Sinica 20: 1113–1115.

Ling L., Xin L. and Guodong C. 2001. Characteristics of landscape pattern changes in middle Heihe River basin. Acta Ecologica Sinica 21: 1217–1224.

McGarigal K. and Marks B.J. 1994. FRAGSTATS: Spatial analysis program for quantifying landscape structure. Forest Science Department, Oregon State University, Corvallis Oregon, USA, 62 pp.

Nanjing Agriculture University 1992. Method for analysis of agricultural chemical parameters in soil. Beijing, Agriculture Press, 420 pp.

Pickett S.T.A. and Cadanasso M. L. 1995. Landscape Ecology, spatial heterogeneity in ecological systems. Science 269: 331–334.

Ritters K.H., O'neill R.V. 1995. A factor analysis of landscape pattern and structure metrics. Landscape Ecology 10: 23–39.

Vincent J. Burke. 2000. Landscape Ecology and species Conservancy. Landscape Ecology 15: 1–3.

Genxu W., Guodong C. et al. 1999. Water resource use and its eco-environmental problems in arid zone of northwest China. Journal of Natural Resources 14: 109–116.

Genxu W., Jian W., Yanqing W., 2002. Analysis of the features of eco-environmental change in the Heihe River Basin in recent 10 year. Geographic Science 22: 527–534.

Xiao D. 1999. Central conception frame of landscape ecology. In: Progress in Landscape Ecological Study, edited by D. Xiao. Hunan Science and Technology Press, Changsha, pp. 8–14.

Xiao D., Rencang B. and Xiuzhe L. 1997. Ecological space theory and landscape heterogeneity. Acta Ecologica Sinica 17: 453–361.