frontiers
in Environmental Science

ORIGINAL RESEARCH
published: 21 March 2022
doi: 10.3389/fenvs.2022.861273

Effects of Different Cropland Reclamation Periods on Soil Particle Size and Nutrients From the Perspective of Wind Erosion in the Mu Us Sandy Land

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Land use changes could notably influence the magnitude and distribution of wind erosion. In recent decades, land reclamation flourished in the Mu Us Sandy Land (MUSL) to supplement cultivated lands (CLs) occupied by urbanization. To analyze the effects of land reclamation on wind erosion, the soil texture and soil nutrients in arable and uncultivated lands should be evaluated. In this study, we collected 54 paired soil samples from CLs and nearby uncultivated lands (NULs) in the MUSL considering land use data pertaining to different phases. Then, the soil particle distribution (PSD) and contents of soil organic carbon (SOC) and total nitrogen (TN) were measured in the laboratory. The results indicated that after 1–15 years (Yr) of cultivation, compared to the NULs, particles ranging from 60 to 400 μm obviously decreased. With increasing number of cultivation years, the wind sorting effects accumulated, and the content of erodible particles susceptible to wind erosion decreased. Among the CLs with different cultivation years, new CLs exhibited the highest erodible particle content, and medium CLs exhibited the lowest erodible particle fraction content. The SOC contents in the medium and fine sand groups among the new CLs was significantly influenced by wind erosion, whereas the TN content was primarily controlled by nitrogenous fertilizer application. After cultivation for longer than 40 years, the total SOC and TN contents in the CLs were significantly higher than those in the NULs. Among the CLs, the wind sorting effects and number of cultivation years obviously influenced the SOC content, whereas the TN content in the CLs was mainly influenced by nitrogenous fertilizer utilization. Rapid urbanization of Shaanxi Province, a new round of national ecological policy adjustments and altered wind environments are the main reasons for the development of new CLs, and a superior location and soil physicochemical properties contribute to the occurrence of old CLs. Based on the above analysis, we propose that conservative cultivation is the key to the protection of new CLs from wind erosion hazards.

Keywords: uncultivated lands, reclamation, soil particle size, nutrients, wind erosion

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Specialty section:
This article was submitted to Soil Processes, a section of the journal Frontiers in Environmental Science

Received: 24 January 2022
Accepted: 03 March 2022
Published: 21 March 2022

Citation:
Liu X, Du H, Li S, Wang T and Fan Y (2022) Effects of Different Cropland Reclamation Periods on Soil Particle Size and Nutrients From the Perspective of Wind Erosion in the Mu Us Sandy Land. Front. Environ. Sci. 10:861273. doi: 10.3389/fenvs.2022.861273

INTRODUCTION

Wind erosion is a common phenomenon in arid and semiarid areas, and wind erosion can influence the soil texture and nutrients by entraining fine particles (Goudie, 1983; Murdock and Frye, 1983; Lawrence and Neff, 2009; Fallahzade et al., 2020; Li et al., 2020b; Du et al., 2021; Zou et al., 2021). This phenomenon has become a worldwide concern because it can cause land degradation and eventually desertification (Zhao et al., 2006; Song et al., 2020; Dou et al., 2022; Mina et al., 2022). The wind erosion process is influenced by many factors, such as human disturbances, soil, weather and vegetation, etc. (Webb et al., 2017; Zou et al., 2021). Among these influencing factors, wind erosion is very sensitive to land use changes *via* anthropogenic activities such as land reclamation (Zhao et al., 2017). Over the last decades, extensive sandy land and grassland areas in arid or semiarid regions in northern China have been converted into croplands to replenish cultivated lands (CLs) occupied by urbanization or to plant grasses to feed more livestock (Shang et al., 2019; Shi et al., 2019). According to a previous estimation, 3.97 million hm^2 of natural grasslands was reclaimed in Northern China from the early 1980s–2010s, the conversion of grasslands to CLs is the main source of new CLs, and CLs converted from grasslands accounted for more than 38.38% of the cropland area in Northern China (Wang and Shi., 2020). Extensive reclamation could affect wind erosion processes to different degrees, and the most obvious changes are observed in terms of the soil texture and nutrient contents.

The soil particle size distribution (PSD), soil organic carbon (SOC), and soil total nitrogen (TN) are essential parameters reflecting the soil texture and nutrients, and these parameters impact the soil bulk density, nutrients, soil carbon absorption, water holding capacity, nutrient cycling, resistance to soil erosion, etc. (Al-Kaisi et al., 2005; Zhou et al., 2008; Colazo and Buschiazzo, 2015; Lozano-Garcia et al., 2017; Alidoust et al., 2018; Bakhshandeh et al., 2019; Liu et al., 2020; Fang, 2021; Seifu et al., 2021). Herein, many studies have adopted these parameters as important indicators to assess wind erosion and land degradation impacts (Fallahzade et al., 2020; Li et al., 2020a; Song et al., 2020; Dai et al., 2022).

The original land use types, tillage methods and cultivation years obviously influence the soil physicochemical properties, such as PSD, SOC and TN contents, etc. (Zhou et al., 2008; Berihu et al., 2016; Kassa et al., 2017; Qi et al., 2018; Qian et al., 2018; Dos Santos et al., 2019; Fallahzade et al., 2020; Xu et al., 2020; Chahal et al., 2021; Chellappa et al., 2021; Fang, 2021). For example, the original land use types and crop types after reclamation directly determine the nutrient levels in soils by inputting different vegetation residues and roots (McDaniel et al., 2014; Chahal et al., 2021). Conventional cultivation without any protective measures could directly destroy soil aggregates and lead to fine particle loss under bombardment by blown sand and wind sorting (Fister and Ries, 2009; Mendez and Buschiazzo, 2010; Abdourhamane Touré et al., 2019), but certain tillage methods, such as irrigation, fertilizer use and protective measures, could improve the soil quality (Bakhshandeh et al., 2019; Shang et al., 2019; Fallahzade et al., 2020; Song et al., 2020; Macedo et al., 2021; Zhang et al., 2021b). In addition to the abovementioned factors, the number of cultivation years is an important factor influencing the soil texture and nutrient content because this factor is related to the agricultural intensity and duration-related effects (Post and Kwon, 2000; Juřicová et al., 2022). However, to date, few studies have examined the relationship between the soil quality and cultivation years, especially from the perspective of wind erosion (Song et al., 2020). To bridge this gap, we adopted the number of cultivation years as an important factor to analyze cropland reclamation effects on the soil texture and nutrient contents from the perspective of wind erosion in the Mu Us Sandy Land (MUSL).

Over the last decade, to supplement CLs occupied by urbanization, large grassland and sandy land areas have been reclaimed for cultivation purposes in the MUSL dominated by large enterprises or government, which has impacted the magnitude and distribution of wind erosion and has resulted in potential land degradation risks. The most obvious results of wind erosion and land degradation include changes in the soil texture and nutrient contents (Du et al., 2018; Bakhshandeh et al., 2019; Dos Santos et al., 2019; Song et al., 2020; Xu et al., 2020; Lyu et al., 2021). Therefore, the soil texture and nutrient content are both important indicators of wind erosion. To determine the effects of cropland reclamation on wind erosion in the MUSL, soil PSD and nutrient contents variations should be analyzed. Herein, the objectives of this study were 1) to compare the differences in soil texture and nutrient content between new CLs and corresponding nearby uncultivated lands (NULs); 2) to analyze the differences in PSD between croplands of different cultivation years; and 3) to reveal the changes in soil nutrient contents (SOC and TN) between CLs with varying reclamation histories. We believe that this study could provide new data for the improvement of soil quality and land development patterns. Furthermore, this study could provide a new perspective to study anthropogenic impacts on wind erosion, and based on the results, we formulate land reclamation suggestions for the local government.

MATERIAL AND METHODS

Study Area

The MUSL, with an area of approximately 48,000 km^2, is located in the agro-pastoral ecotone and south of the Ordos Plateau (**Figure 1**). This area is controlled by a typical continental semiarid climate (Zhu et al., 1980), and the mean annual precipitation ranges from 150 mm in the northwest to 450 mm in the southeast. Precipitation exhibits a high interannual variability, and approximately 70% of rainfall occurs from June to August. The annual average temperature ranges from approximately 6.0–8.5°C, with monthly average temperature of 22°C in July and -11°C in January (Huang et al., 2009). The spring climate is characterized by dry and strong wind environments (Zhu et al., 1980; Liang and Yang, 2016), and nearly all dust storms occur during this season.

The main land use types in the MUSL include grasslands, CLs, shrublands and sandy lands, and sandy lands are dominated by mobile, semi-fixed, and fixed dunes (Liu et al., 2016). Mobile dunes are distributed in the western

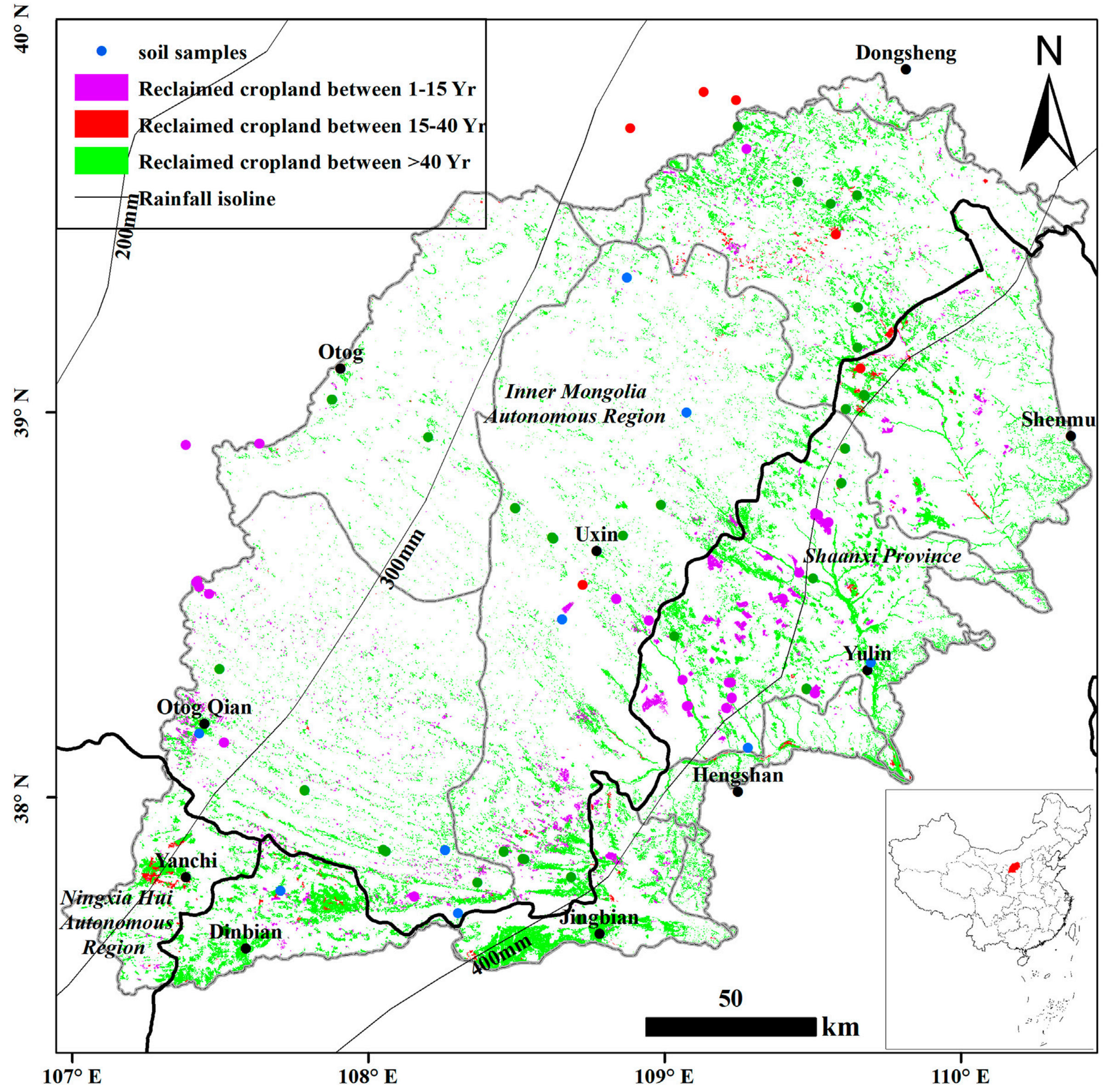

FIGURE 1 | Location of the MUSL, distribution of the soil samples and areas with the various agricultural reclamation ages. The green, red, and purple dots represent soil samples that have been farmed for more than 40 years, 15–40 years, and 1–15 years, respectively.

and eastern regions of this sandy land at heights ranging from 5 to 10 m (Zhu et al., 1980; Wang et al., 2005), while fixed or semi-fixed dunes with heights ranging from 5 to 15 m are mainly distributed in the interior of the MUSL (Huang et al., 2009; Liu et al., 2016). Atop fixed dunes and at the foot of semi-fixed dunes, *Calligonum* and *Agriophyllum* are the major plants (Liang and Yang., 2016), and *Sanina*, *Tamarix*, *Hippophae* and *Salix* mainly grow in interdune lowlands. CLs were reclaimed in the lowlands occurring between dunes and riparian areas, and these lands were mainly converted from grasslands. Maize and potato are the dominant agrotypes, especially in the newly established CLs, which are largely distributed in the east and south of the MUSL (Li et al., 2017; Li et al., 2019). The soil types in the MUSL include silty clay, clay loam, silt loam, loam, sandy clay loam, sandy loam, and loamy sand.

Soil Sample Collection and Measurement

According to the land use changes of different phases in the MUSL, we classified the number of reclamation years into three phases as follows: old (>40 years (Yr)), medium (15–40 Yr) and new (1–15 Yr) (Li et al., 2019). Soil samples were collected based on the different reclamation phases. A soil auger was employed to collect soil samples in CLs and corresponding NULs served as references. The diameter of the auger was 15 cm, and the depth of the soil samples ranged from 0 to 40 cm, with three replicates in each plot to form a composite

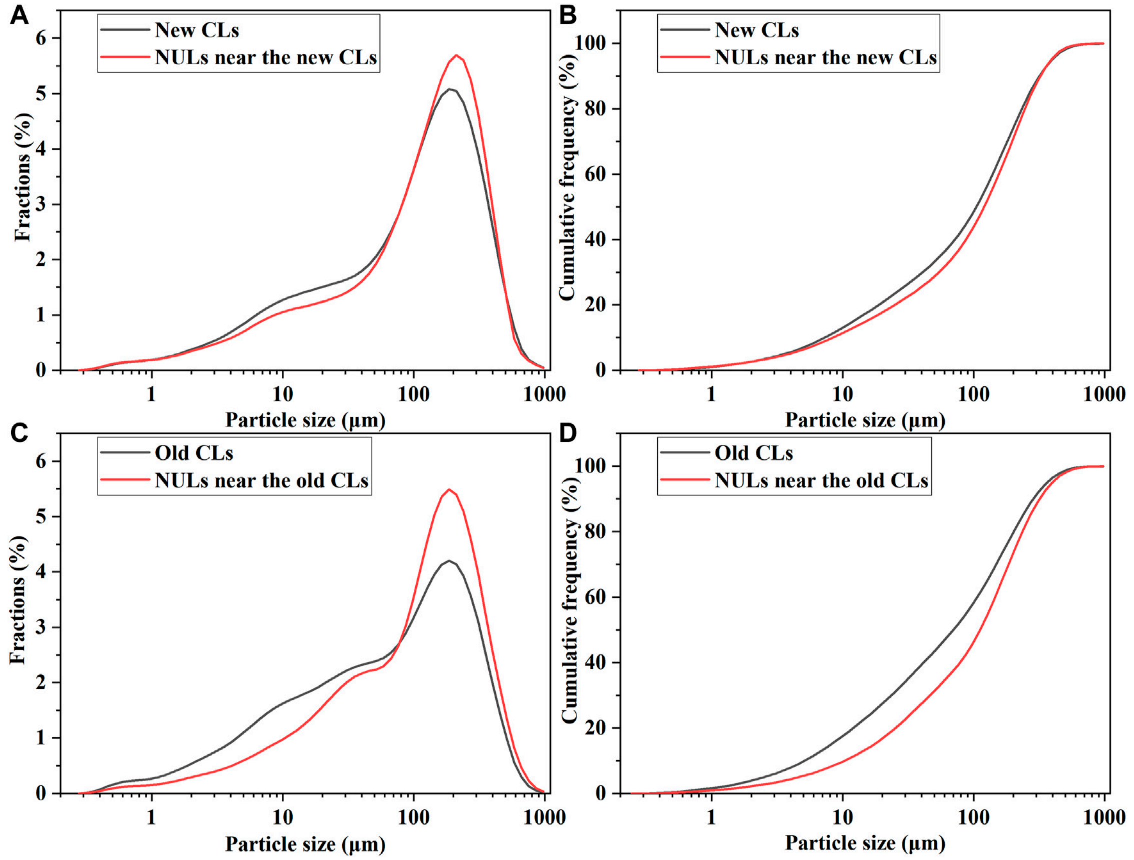

FIGURE 2 | (A,B) Soil particle size distributions in the new CLs and NULs; **(C,D)** soil particle size distributions in the old CLs and NULs.

sample. Fifty-four paired samples were collected in 2018. The numbers of paired soil samples in the new, medium and old CLs and their corresponding NULs were 19, 7 and 28, respectively. These samples were sealed in zip-locking plastic bags and transported to the laboratory. Then, soil samples were divided into two subsamples, one subsample was used to measure the PSD and the other subsample was applied to analyze SOC and TN contents.

The PSDs of the preprocessed soil samples were measured on a Malvern Mastersizer-3000 manufactured by Malvern Instruments Ltd., Malvern, United Kingdom. The measurement range of the Malvern 3,000 device extends from 0.01 to 3,500 μm. Chemical dispersants were not applied in particle size analysis to retain the PSDs of the samples as close to those of the field samples as possible. With the use of the Malvern 3,000 instrument, we obtained the PSDs of the collected soil samples.

The SOC and TN contents were tested with a Vario Macro-cube (Elementar Inc., Germany). The SOC content was measured through digestion with potassium dichromate and back-titration with 0.025 mol/L ferrous ammonium sulfate following Kalembasa and Jenkinson (1973). To compare the abundance characteristics of SOC and TN among different soil particle diameters, the soil samples were sieved into six particle diameter groups by a sieve shaker for 10 min with a vibration frequency of 300 times per minute. The particle diameters of these six groups were <32 μm (fine silt), 32–50 μm (coarse silt), 50–100 μm (micro sand), 100–315 μm (fine sand), 315–400 μm (medium sand) and >400 μm (coarse sand), and the SOC and TN contents in each soil group were measured.

Data Analysis

The normality and homogeneity of the variance in the data were assessed with the Kolmogorov-Smirnov (K-S) test. The paired-sample *t*-test was performed to evaluate the significance of the differences in the SOC and TN contents between the CLs and NULs across the various particle diameter groups. The effects of the cultivation age on the SOC and TN contents in the CLs were assessed *via* one-way analysis of variance (ANOVA) followed by least significant difference (LSD) testing ($p < 0.05$). All statistical analyses were performed in Statistical Product and Service Solutions (SPSS) software version 21.0 (IBM Inc.).

RESULTS

Soil Particle Size Distributions in the New CLs and NULs

The soil PSDs in the new CLs and NULs were obtained with the Malvern 3,000 device (**Figures 2A,B**). The results indicated that the PSDs in the CLs and NULs all exhibited unimodal distributions. Particles with a diameter between 80 and 400 μm occupied the largest fractions in both the new CLs and corresponding NULs, at 54 and 59%, respectively. The soil particles in the new CLs were finer than those in the NULs because the median diameter (d_{50}) in the new CLs reached 105 μm, whereas d_{50} reached 120 μm in the corresponding NULs.

$$u_{*t}\left(d_s\right) = \sqrt{a_1\left(\frac{\rho_p}{\rho_a} g d_s + \frac{a_2}{\rho_a d_s}\right)} \quad (1)$$

According to the threshold friction velocity (TFV) calculation method proposed by Shao (2001) (**Eq. 1**), soil particles with a diameter between 60 and 200 μm are easily eroded by wind, and the entrainment wind speed could increase for finer or coarser particles. According to our findings, particles ranging from 60 to 400 μm were the most easily eroded. The easily erodible particles in the new CLs obviously occurred less frequently than those in the NULs, at 59 and 64%, respectively. In addition, the CLs and NULs exhibited similar coarse particles (a particle size larger than 400 μm) content, while the former exhibited higher fractions of fine particles (a particle size smaller than 60 μm) than did the latter. Particles with a diameter between 60 and 400 μm were entrained by wind, whereas finer and coarser particles were retained. The PSD results further illustrate that the new CLs in the MUSL were more severely impacted by wind erosion processes than were the NULs.

Soil Particle Size Distributions in the Old CLs and NULs

The PSDs in the old CLs and NULs are plotted in **Figures 2C,D**, respectively, which show that the soil particles in the old CLs were noticeably finer than those in the corresponding NULs as the d_{50} values in the old CLs and NULs were 67 and 115 μm, respectively.

As described above, 60 and 400 μm comprised the demarcation points between easily erodible and non-erodible particles. The content of particles smaller than 60 μm in the old CLs was 46%, which was significantly higher than that in the corresponding NULs (34%). The content of coarse particles with a diameter larger than 400 μm in the old CLs and NULs was similar, at 4 and 3%, respectively. The PSD results for the old CLs and NULs indicated that the easily erodible particles in the old CLs occurred less frequently than those in the NULs, and the content of non-erodible particles (a particle size smaller than 60 μm or larger than 400 μm) was higher than that in the NULs. This result indicates that the old CLs were significantly more influenced by wind erosion processes than were the NULs.

Soil Particle Size Distributions in the CLs of the Different Cultivation Years

The PSDs in the CLs of the different cultivation years are shown in **Figure 3**. The PSDs in both the new and old CLs were unimodal, and the PSDs in the medium CLs were bimodal. The peaks of the PSDs in the new and old CLs ranged from 100 to 300 μm, while the peaks of the PSDs in the medium CLs ranged from 7 to 20 μm and 50–200 μm, respectively. Compared to the soil particles in the new and old CLs, the soil particles in the medium CLs were finer and more poorly sorted, and the d_{50} value of the particles in the medium CLs was 47 μm, while those in the new and old CLs reached 67 and 105 μm, respectively. This suggests that the PSDs in the medium CLs were the most severely sorted by wind stresses.

Among the CLs of the different cultivation years, the new CLs exhibited the largest erodible particle (60–400 μm) fractions, and these fractions occupied approximately 59% of the total mass, while the content of erodible particles in the medium CLs was the lowest, at only 41%. This demonstrates that the soils in the new CLs were the most erodible, and with increasing effects of wind erosion on the soils, the erodible particles decreased year by year. After cultivation from 15 to 40 Yr, the content of erodible particles decreased to 41%. The erodible soil particle content in the new and medium CLs further supports the finding that the accumulated wind erosion effects in the medium CLs are the most severe. However, with increasing cultivation years, the wind erosion effects weakened, and the anthropogenic effects (such as fertilization application and deep plowing) gradually exceeded the wind erosion effects. In addition, the shelter forests surrounding the old CLs could trap more wind erosion-derived sediments. Therefore, the old CLs usually attained higher content of erodible particles than those in the medium CLs. Although the old CLs exhibited a higher erodible particle content than that of the medium CLs, it cannot be stated that the old CLs are more erodible than are the medium CLs simply because the soil erodibility is also affected by the organic matter content according to wind erosion models, such as the Revised Wind Erosion Equation (RWEQ) proposed by Fryrear et al. (1998). In the following sections, the SOC and TN contents in the CLs and NULs are examined.

Differences in the SOC and TN Contents Between the New CLs and Corresponding NULs

The SOC and TN contents in the soil samples collected in the new CLs and NULs were tested (**Table 1**). **Figures 4A,B** display that neither the total SOC nor total TN content was significantly different at a confidence level of 0.05 between these two land use types.

To further examine the differences in the SOC and TN contents between the new CLs and NULs, the nutrient contents in the different particle size groups were also analyzed. **Table 1** and **Figures 4A,B** show that soil groups encompassing fine particles generally exhibited higher nutrient contents, and the differences between two adjacent groups increased with decreasing particle size from medium sand on. The SOC contents in the medium sand, fine sand and fine silt groups between the two land use types were significantly different ($p < 0.05$), and the nutrient contents in the other soil groups of both land use types revealed no significant differences at the same confidence level. Based on the above analysis, medium and fine sand particles are highly erodible by wind, and the contents of both soil groups were lower in the new CLs (**Figure 2A**). Therefore, the SOC contents in both soil groups in the new CLs were significantly lower than those in the corresponding NULs. Moreover, the horizontal sand flux could destroy soil aggregates and increase SOC exposure and mineralization, thus

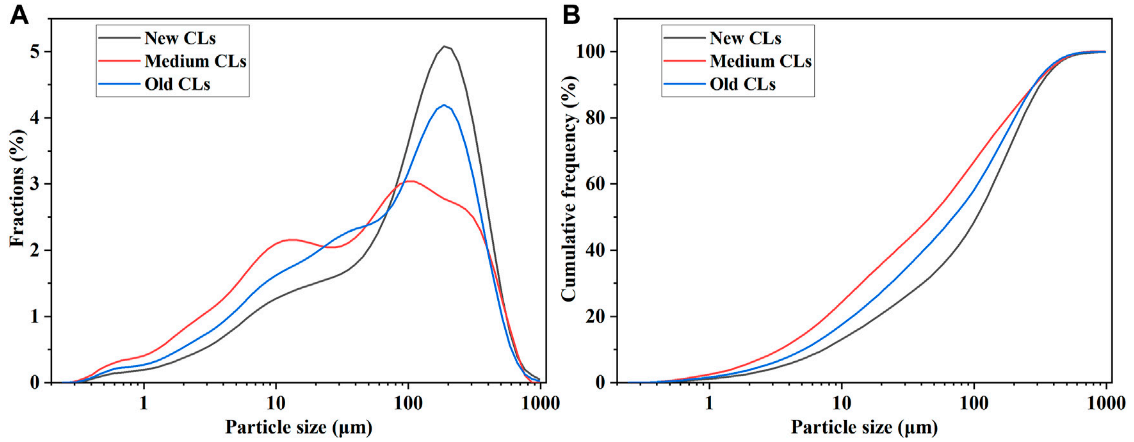

FIGURE 3 | (A) Soil particle size distributions in the new, medium and old CLS, and **(B)** cumulative frequency of soil particle size distributions in the new, medium and old CLS.

TABLE 1 | SOC and TN contents between the new CLs and NULs.

Nutrients	Land use types	Total soil samples	Coarse sand	Medium sand	Fine sand	Micro sand	Coarse silt	Fine silt
SOC (g/kg)	CLs	5.41 ± 2.94	2.81 ± 1.37	1.74 ± 0.66	2.07 ± 0.9	4.17 ± 1.51	9.15 ± 4.24	10.08 ± 4.64
	NULs	5.72 ± 2.76	2.49 ± 1.21	2.46 ± 1.14	3.36 ± 1.5	4.5 ± 1.68	9.84 ± 4.57	14.83 ± 5.33
TN (g/kg)	CLs	0.63 ± 0.25	0.38 ± 0.18	0.35 ± 0.17	0.34 ± 0.16	0.61 ± 0.28	0.9 ± 0.44	1.25 ± 0.6
	NULs	0.6 ± 0.25	0.31 ± 0.14	0.29 ± 0.13	0.36 ± 0.16	0.6 ± 0.24	0.78 ± 0.29	1.38 ± 0.64

Note: Data are means ± SD.

accelerating the SOC decomposition rate, which enhances SOC content reduction in the fine particle soil groups. These processes were verified based on the SOC content in the fine silt fraction in the new CLs, which was obviously lower than that in the NULs.

In contrast to the SOC content, the TN content may be influenced by nitrogenous fertilizer application during cultivation activities. During the long-term cultivation of maize and potatoes, nitrogenous fertilizers was applied in large quantities (Shi et al., 2019), which could supplement the TN content lost due to wind erosion. Impacted by application of nitrogenous fertilizer, the TN content in the new CLs did not significantly differ from corresponding NULs in terms of neither the total contents nor the contents in the different particle size groups.

Differences in the SOC and TN Contents Between the Old CLs and NULs

Table 2 shows SOC and TN contents in different particle size groups between the old CLs and NULs. The total SOC and TN contents in the old CLs were all significantly higher than those in the NULs at a confidence level of 0.05, but the total TN contents between these two land use types differed even at a confidence level of 0.01 (**Figures 4C,D**, respectively). This suggests that the old CLs possessed higher soil fertility levels than did the NULs.

The nutrient contents across the different soil particle size groups in the old CLs and corresponding NULs differed from those in the new CLs and corresponding NULs. The SOC and TN contents in the fine silt group of the old CLs were significantly higher than those in the NULs at a confidence level of 0.05 (**Figures 4C,D**, respectively). The reason that the nutrient contents in the old CLs are higher than those in the corresponding NULs is that the former contains higher fractions of fine particles, and soil groups with finer particles contain higher nutrient contents. Except for the fine silt, the nutrient contents in the other particle size groups between the old CLs and corresponding NULs did not significantly differ at the same confidence level. Furthermore, in the groups with coarser particles (coarse, medium and fine sand), the differences in the SOC and TN contents between these two land use types were small. This indicates that the wind erosion effects on the old CLs are weakened, because the nutrient contents in the erodible particles are not significantly reduced. The differences in the nutrient contents between the old CLs and corresponding NULs indicate that after cultivation for longer than 40 Yr, the wind erosion effects were weakened, and the soil nutrients lost *via* wind erosion could be supplemented through human disturbance (such as fertilization) and inputs of decomposing plant residues.

SOC and TN Contents in the CLs With the Different Cultivation Years

The ANOVA results demonstrated that the number of cultivation years exerted a significant impact on the SOC content in the medium sand, fine sand, micro sand and fine silt fractions. However, at the 0.05

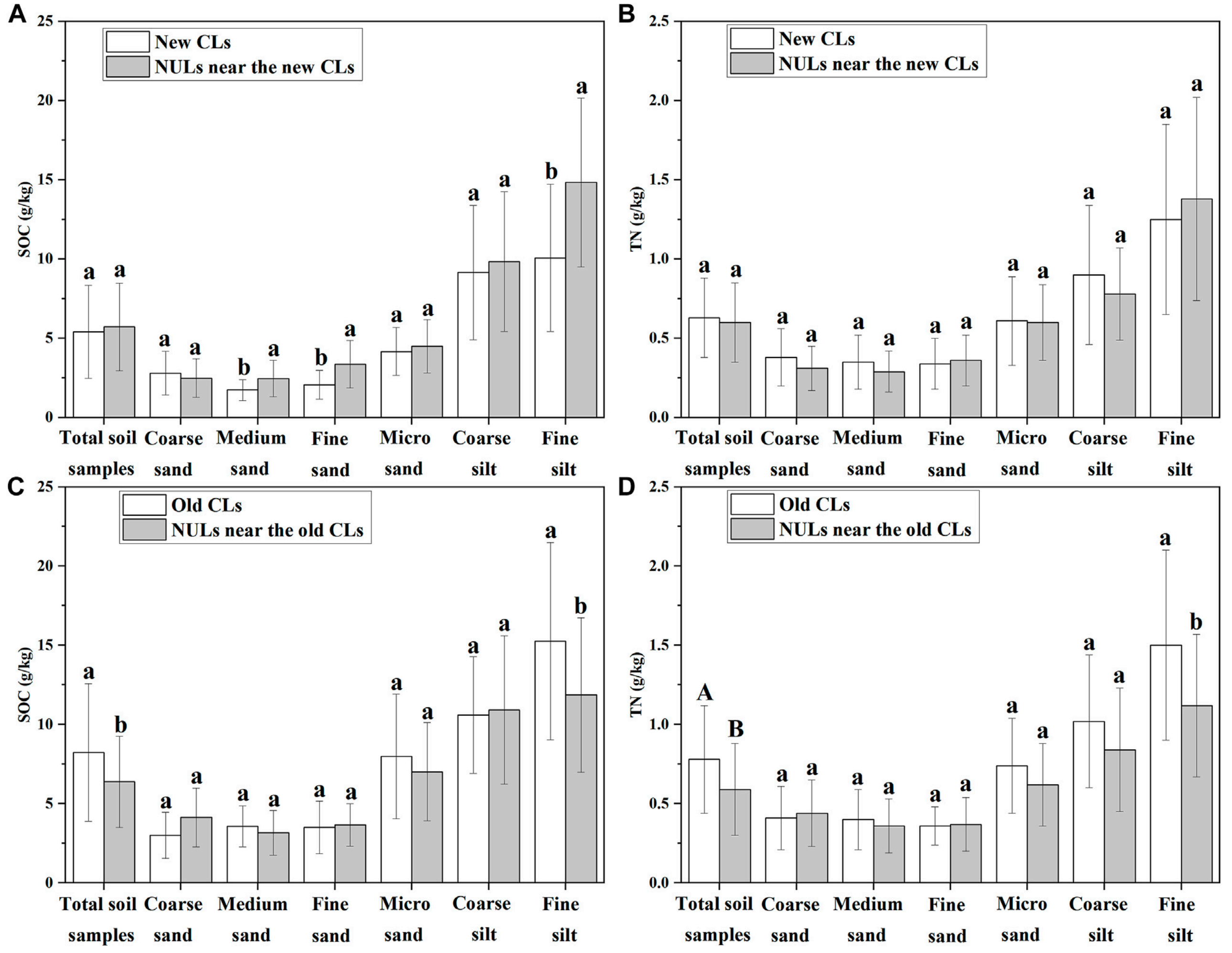

FIGURE 4 | (A,B) SOC and TN contents in the different particle diameter groups in the new CLs and NULs; **(C,D)** SOC and TN contents in the different particle diameter groups in the old CLs and NULs. The upper and lowercase letters denote the differences in the SOC and TN contents between the CLs and corresponding NULs based on paired-sample *t*-tests at confidence levels of 0.01 and 0.05, respectively.

TABLE 2 | SOC and TN contents between the old CLs and corresponding NULs.

Nutrients	Land use types	Total soil samples	Coarse sand	Medium sand	Fine sand	Micro sand	Coarse silt	Fine silt
SOC (g/kg)	CLs	8.23 ± 4.34	3 ± 1.45	3.58 ± 1.3	3.51 ± 1.66	7.99 ± 3.93	10.61 ± 3.68	15.26 ± 6.23
	NULs	6.39 ± 2.87	4.14 ± 1.85	3.17 ± 1.41	3.67 ± 1.33	7.02 ± 3.1	10.91 ± 4.69	11.86 ± 4.87
TN (g/kg)	CLs	0.78 ± 0.34	0.41 ± 0.2	0.4 ± 0.19	0.36 ± 0.12	0.74 ± 0.3	1.02 ± 0.42	1.5 ± 0.6
	NULs	0.59 ± 0.29	0.44 ± 0.21	0.36 ± 0.17	0.37 ± 0.17	0.62 ± 0.26	0.84 ± 0.39	1.12 ± 0.45

Note: Data are means ± SD.

confidence level, there was no significant difference in the TN content among the CLs of the varying cultivation years. **Figure 5** shows the differences in the SOC and TN contents among the CLs of the varying cultivation years, and it is found that the SOC content in the old CLs is significantly higher than that in the new CLs in most particle size groups at the 0.05 confidence level.

Due to the higher content of fine particles and longer cultivation period, the SOC content in the old CLs was obviously higher than that in the new CLs (**Table 3**). The SOC content in the erodible particles (medium sand, fine sand, and micro sand fractions) in the CLs was obviously influenced by the number of cultivation years, whereas the

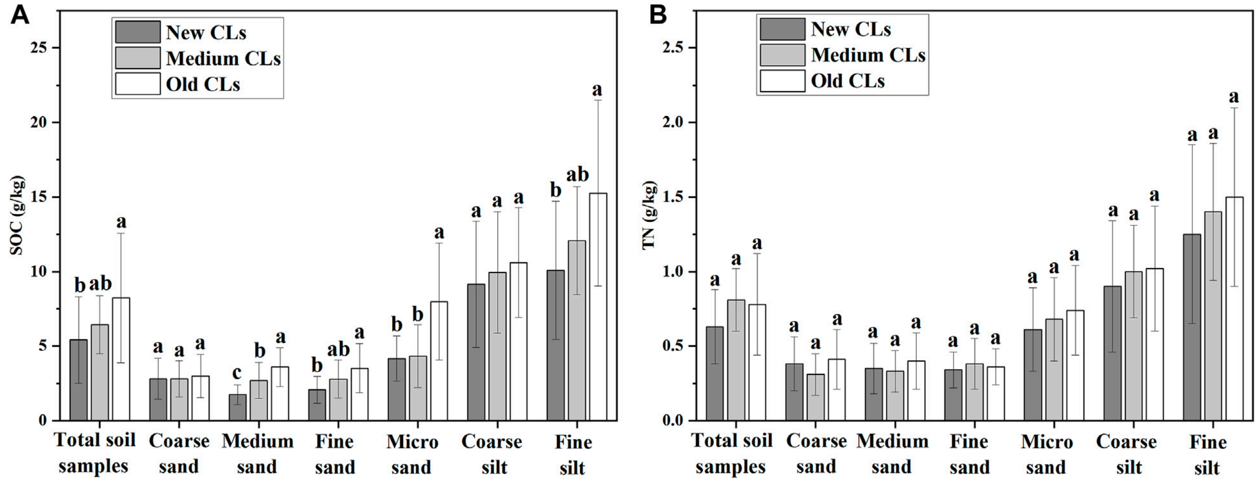

FIGURE 5 | (A) SOC content in the different particle size groups in the new, medium and old CLs, and **(B)** TN content in the different particle size groups in the new, medium and old CLs. The lowercase letters denote the differences in the SOC and TN contents among the CLs of the different cultivation years based on one-way analysis of variance followed by LSD tests ($p < 0.05$).

TABLE 3 | SOC and TN contents in the CLs with the different cultivation years.

Nutrients	Cultivation phases	Total soil samples	Coarse sand	Medium sand	Fine sand	Micro sand	Coarse silt	Fine silt
SOC (g/kg)	New	5.41 ± 2.94	2.81 ± 1.37	1.74 ± 0.66	2.07 ± 0.9	4.17 ± 1.51	9.15 ± 4.24	10.08 ± 4.64
	Medium	6.43 ± 1.94	2.81 ± 1.22	2.69 ± 1.21	2.78 ± 1.27	4.32 ± 2.11	9.95 ± 4.08	12.07 ± 3.63
	Old	8.23 ± 4.34	3 ± 1.45	3.58 ± 1.3	3.51 ± 1.66	7.99 ± 3.93	10.61 ± 3.68	15.26 ± 6.23
TN (g/kg)	New	0.63 ± 0.25	0.38 ± 0.18	0.35 ± 0.17	0.34 ± 0.16	0.61 ± 0.28	0.9 ± 0.44	1.25 ± 0.6
	Medium	0.81 ± 0.21	0.31 ± 0.14	0.33 ± 0.14	0.38 ± 0.17	0.68 ± 0.28	1 ± 0.31	1.4 ± 0.46
	Old	0.78 ± 0.34	0.41 ± 0.2	0.4 ± 0.19	0.36 ± 0.12	0.74 ± 0.3	1.02 ± 0.42	1.5 ± 0.6

Note: Data are means ± SD.

SOC content in the non-erodible particles (except for fine silt) was not influenced by the number of cultivation years. PSD analysis revealed that particles ranging from 60 to 400 μm were obviously influenced by wind erosion. Consequently, the differences in SOC content in the erodible particles among the CLs could be attributed to wind erosion and the number of cultivation years. Wind erosion leads to a loss of SOC adhering to erodible particles in the CLs, and the different cultivation periods magnify the difference in SOC content among the CLs. The TN content in the CLs was not significantly influenced by the number of cultivation years regardless of the total contents or the contents across the different soil particle groups, and the TN content did not seem to be influenced by wind erosion. We recognized that fertilization eliminated or reduced the TN loss induced by wind erosion. The results for the SOC and TN contents in the CLs illustrate that the SOC content in the CLs was mainly affected by wind erosion and number of cultivation years. However, impacted by fertilization, the TN content in the CLs of the different cultivation years did not exhibit a clear distinction in the same particle size group.

DISCUSSION

Driving Forces for Reclamation of the New CLs

Land reclamation in the MUSL was led by national macro-policies, regional development policies, or socioeconomic development (Liu et al., 2010; Li et al., 2017; Shi et al., 2019; Zhang and Deng, 2020; Feng et al., 2021; Miao and Xue, 2021). The reasons for land reclamation in the MUSL from 2000–2015 were examined based on policies and amount of new CLs.

From 2000 to 2010, the Chinese government implemented several ecological projects, such as the Grain for Green Project (GTGP) and the Grazing Forbidden Project, which decreased the total area of CLs, while 29.09 km^2 of new CLs was reclaimed in the southern MUSL during this period (Li et al., 2019). During the period from 2010 to 2015, CLs were mostly converted from grasslands, and the corresponding area in the MUSL increased by 411.29 km^2, which was primarily attributed to rapid urbanization of Shaanxi Province and a new round of national ecological policy adjustments (Li et al., 2017; Shi et al., 2019).

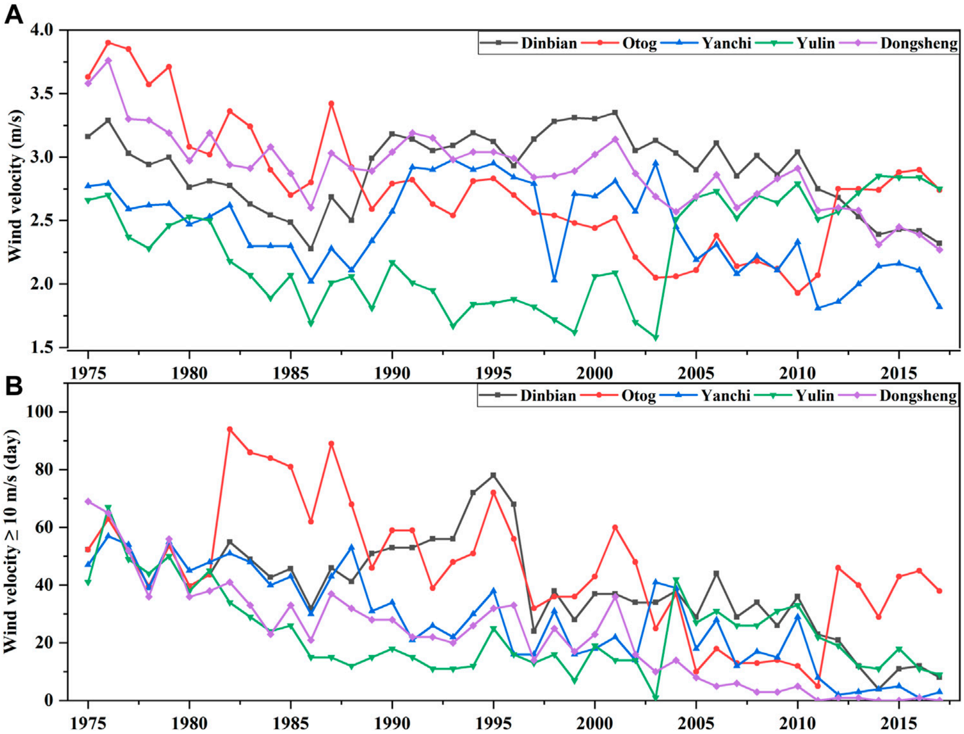

FIGURE 6 | (A) Annual average wind velocity, and **(B)** days with a wind speed higher than 10 m/s from 1975 to 2017 in Dinbian, Otog, Yanchi, Yulin and Dongsheng.

Except for macro-policies and regional development policies, the variation in wind environments in the MUSL is another factor of land reclamation. In regard to the strong wind environments in agro-pastoral ecotone, CLs are recognized as the main dust sources due to wind erosion. Therefore, the wind speed is considered the most important factor controlling wind erosion (Wang et al., 2015; Jiang et al., 2018; Zhang et al., 2021a).

From 1975 to 2017, the annual average wind speed in the MUSL fluctuated downward. From 1975 to 1986 and 2000 to 2011, the declining trend was even more pronounced (**Figure 6A**). In addition to the annual average wind speed, the annual gale days indicated a daily maximum wind speed higher than 10 m/s, which is the erosive wind speed in northern China and is also an important indicator of wind erosion (Du et al., 2017). **Figure 6B** shows that the number of annual gale days decreased from 1975 to 2017 and fell to 0 after 2011 at certain locations (**Figure 6B**). From 1975 to 2000, natural disasters caused by unreasonable human activities such as wind erosion and desertification became increasingly serious (Zeng et al., 2014; Feng et al., 2021). Subsequently, the GTGP policy was implemented, and grasslands and woodlands were recovered (Li et al., 2019). After 2000, the desertification trend slowed, and wind erosion events further decreased due to the decrease in wind speed and number of gale days. Under these conditions, humans reclaimed land based on economic interests after 2011.

Rationality of the Presence of Old CLs

More than 85.31% of the CLs in the MUSL has been cultivated for longer than 40 Yr due to their superior location and soil physicochemical properties. In the MUSL, the water supply and fragile ecological environment are two major factors constraining agricultural development. The majority of the CLs in the MUSL receives less than 400 mm of precipitation per year (**Figure 1**), which suggests that most CLs are unsuitable for cultivation. However, most old CLs are distributed in the lowlands occurring between tall dune chains and river valley terraces, where soil water sufficiently occurs or the area is easily irrigated. In addition, the wind speed in these areas is lower than that in other areas, which indicates that the wind erosion influence is limited. The PSD and nutrient contents in the soil samples further supported this result. The above reason denotes that the presence of these old CLs in the MUSL is reasonable.

Measures for Sustainable Development of New CLs

Large areas of new reclaimed CLs in high-wind energy environments in the MUSL could exert an enormous pressure on the fragile ecological environment. Once these new CLs are unreasonably managed, the soil quality would decline rapidly and lead to abandonment of these CLs. Therefore, the establishment of new CLs is not conducive to the sustainable development of regional agriculture and poses a potential threat to the reduced desertification trend (Yan et al., 2015; Feng et al., 2021). However, when CLs were cultivated for longer than 15 Yr, the soil quality was recovered and enhanced (**Figures 3**, **5**). Therefore, long-term healthy cultivation of new CLs comprises the key to maintaining the sustainable development of new CLs. In this study, conservative cultivation methods protecting new CLs were proposed based on the above analysis of the effects of different cultivation years on the soil quality.

Measures should be implemented to protect fine fractions by weakening wind erosion effects. The soils in the MUSL exhibit poor cohesion and are easily eroded. In addition, the average sand-driving wind persists for 49–60 days per year (Wu et al., 2011). In winter and spring, due to the lack of vegetation protection, strong winds easily entrain soil particles. Once fine soil particles rich in nutrients are eroded by wind, it is very difficult to recover the soil quality within a short time. Conservation tillage practices such as ridge tillage and shelterbelts have been proved to be effective to weaken wind erosion and protect fine particles (Jia, 2013; Su et al., 2021; Xiao et al., 2021). Ridge tillage can decrease wind erosion on a field scale (Liu et al., 2006), and shelterbelts comprising shrubs and trees can not only reduce the downwind wind speed but can also capture fine particles suspended in the atmosphere (Chang et al., 2021; Xiao et al., 2021). Therefore, protective measures encompassing ridge tillage implemented in CLs and shelterbelts construction near CLs should be adopted to reduce soil wind erosion.

CONCLUSION

Based on land use data pertaining to different phases, soil samples were collected in CLs of different cultivation years and corresponding NULs. The PSDs and SOC and TN contents in the soil samples retrieved from CLs and corresponding NULs were analyzed. Using measured data, we analyzed the effects of different cropland reclamation periods on soil physicochemical properties from the perspective of wind erosion.

In the MUSL, the diameter of erodible particles susceptible to wind erosion ranged from 60 to 400 μm. Due to wind sorting effects, the content of erodible particles decreased in CLs compared to their corresponding NULs with increasing cultivation years, and the content of decreased erodible particles was 5% in the new CLs, while it was 11% in the old CLs. However, the content of fine particles with a diameter smaller than 60 μm increased in CLs with the number of cultivation years, and the content of increased fine particles in the new and old CLs was 5 and 12%, respectively. Wind erosion leads to a loss of the SOC content in new CLs, particularly in the medium and fine sand fractions. After 40 years of cultivation, the total SOC and TN contents in the CLs were significantly higher than those in the corresponding NULs. The SOC content was influenced by wind erosion and number of cultivation years, whereas the TN content was influenced by nitrogenous fertilizer application. The analysis results indicate that the new CLs were easily degraded and impacted by wind erosion, and if CLs could be suitably cultivated for a long period, usually exceeding 15 Yr, the soils were no longer remarkably affected by wind erosion, and the soil quality could be recovered and stabilized.

Based on the analysis results, we propose that conservative cultivation is the key to protecting new CLs from wind erosion hazards. After healthy long-term cultivation, new CLs could become sustainable arable lands.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

XL: Conceptualization, Methodology, Writing-Original draft preparation HD: Conceptualization, Collecting samples, Investigation, Supervision, Validation SL: Investigation, Collecting samples, TW: Editing, Writing-reviewing, YF: Data curation, Experimentation.

FUNDING

This research is supported by the Consultation and Evaluation Project of the Academic Divisions of the CAS (Grant No. 2019-ZW09-A-032), The Ningxia Hui Autonomous Region key R&D project, “Key technology research and model establishment of grass and animal industry function promotion in Yanchi County based on water resources carrying capacity” (Grant No. 2020BBF02003), and The major science and technology project in Inner Mongolia Autonomous Region, “Research on near-natural restoration technology and industrialization demonstration of sandy ecosystem” (Grant No. 2019ZD003).

ACKNOWLEDGMENTS

We thank Dr. Caixia Zhang for her help in carrying the grain size analysis, and also thank Technology Service Center of CAREERI, CAS for the sample testing service.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.