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ORIGINAL ARTICLE

Monitoring grassland reclamation in the Mu Us Desert using remote sensing from 2010 to 2015

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Abstract
New conversion from grassland to cropland was effectively curbed with the implementation of the Grain-to-Green Program (GTGP) in northern China from 1999 to 2010. However, the phenomenon of grassland reclamation has significantly increased since 2010. Here, the latest trend of conversion from grassland to cropland was evaluated using a Landsat dataset from 2010 and 2015 in the Mu Us Desert (MUD) of northern China. An object-based approach was chosen to classify grassland and farmland information, and the classification accuracy was 98.33% based on 120 cropland verification points, which were obtained through available Google Earth and field survey data. The area of grassland reclamation increased by 411.29 km^2 from 2010 to 2015 and was mainly distributed in the southeastern and southwestern parts of the MUD, accounting for 9.78% of the total cropland area in 2015. There were two ways to reclaim grassland, including herdsmen cultivating grasslands on their own pastures and grassland reclamation projects implemented by enterprises under the direction of local governments. Exposed cultivated land is more susceptible to wind erosion and eventually leads to decreasing agricultural productivity and desertification. Therefore, strategies to reduce wind erosion on reclaimed grassland in the study area should be implemented as soon as possible, including several alternative cultivation systems and ridge tillage. If conditions permit, conservation tillage should be changed in the MUD.

Keywords Grassland reclamation · Wind erosion · Remote sensing · Mu Us desert

Introduction

Grasslands are great ecosystems around the world and occupy 22.10% of the global land area, excluding areas of Greenland and Antarctica (Suttie et al. 2005; White et al. 2000). In temperate grasslands, only 4.6% of native temperate grasslands are conserved globally within protected areas (Carbutt et al. 2017), which is lower than the percentage of those in all other ecosystems (Hoekstra et al. 2005). A large number of grasslands have been converted to other land covers, such as crops, mixed farming, artificial pastures and desert, due to climate change and increased human activity (Suttie et al. 2005). In addition, grassland reclamation has gradually become one of the greatest threats to grassland degradation (Stephens et al. 2008).

Grassland reclamation occurred prior to the 1950s in temperate grasslands (Assessment 2005). At present, grassland reclamation mainly occurs in the tropics, with many tropical grasslands and savannas undergoing change. The expansion of grassland reclamation in North America (Wright and Wimberly 2013), South America (Gavier-Pizarro et al. 2012), Asia (Qi et al. 2012) and Southern Africa (Maeda et al. 2010) creates new pressures on global grassland ecosystems.

Crop fields that are transformed from grassland reclamation are generally of larger dimension and exceed 1.00 km^2, a large proportion of which is fallow during the windy spring season (Hoffmann et al. 2011). Bare and ploughed soils are more susceptible to wind erosion than grasslands (Reiche et al. 2015). For example, 75% of the total dust emissions originated from cropland (5% of the area) and only 25% of dust emissions originated from grassland (95% of the area) in the Xilingol steppe in 2006

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based on Hoffmann et al.'s (2011) estimation (Reiche et al. 2015). Therefore, croplands are considered to contribute extraordinarily to total dust emissions and soil degradation in temperate grasslands (Hoffmann et al. 2011).

Grasslands are one of the most dominant land use types in China, covering approximately 2.15×10^6 km^2 and accounting for 22.39% of the total land area (Bureau, 2016). The organized reclamation of grassland can be traced back to the Qin and Han Dynasties (221 BC–220 AD) in Northern China (Liu et al. 2003, 2010). Since the 1980s, the intensity of grassland reclamation has reached a peak with the increase in population and the improvement in production technology in China. In addition, cropland increased by 2.83×10^4 km^2, with reclaimed cropland concentrated mainly in the farming–forestry ecotones of Northern China from the late 1980s to 2000 (Liu et al. 2014). Various natural disasters began to emerge in this period, such as soil wind erosion, dust storms, desertification and droughts. Consequently, the Grain-to-Green Program (GTGP) was implemented with the aim of reducing wind erosion by restoring grassland and forest (Ouyang et al. 2016), and cropland decreased by 1.02×10^4 km^2 from 2000 to 2010 in China (Liu et al. 2014). However, over the last few years (since 2010), grasslands (accounting for 64.00%) and unused lands (accounting for 21.90%) have been reclaimed, causing the cropland area to rapidly increase in Northern China (Ning et al. 2018). In recent decades, grassland reclamation has become one of the main types of land use change in the temperate grasslands of Northern China.

Similar fluctuations from grassland to cropland in Northern China also occurred from 1965 to 2010 in the Mu Us Desert (MUD) (Li et al. 2017). However, we have discovered through field investigations over the past 5 years in the MUD that grassland reclamation has increased dramatically. Such reclamation may become the greatest threat to the steppe area of the MUD. However, the areal, pattern and potential effects of grassland reclamation on the MUD in the past 5 years are unclear.

Remote sensing is an effective and convenient tool for monitoring and assessing land use and land cover across a large region. Effective and real-time satellite images can be easily acquired. In particular, multispectral satellite imagery, such as that provided by Landsat series images (with a re-visit time of 16 days), is a precious resource for the timely monitoring of surface processes (Wang et al. 2012). In the present study, we use Landsat TM/OLI data from 2 years (2010 and 2015) covering the entire MUD to detect and evaluate the latest trend in the conversion from grassland to cropland. The objectives of this study are to quantify the latest area of grassland reclamation and analyse the possible ecological hazards in the MUD.

Method and materials

Study area

The MUD covers approximately 48,288 km^2 (Li et al. 2017) and is located in a transitional zone between typical steppe and desert steppe regions in Northern China (Fig. 1a). Elevations vary from 902 to 1684 m above mean sea level (Yan et al. 2015) (Fig. 1b). Three types of landforms dominate the MUD: hard hills caused by erosion and the ageing of bedrock, sandy uplands consisting of sediments accumulated during the Quaternary period, and lower wetlands due to cuts in Quaternary sediments by rivers and streams (Wu and Ci 2002). There is an abundance of surface water and groundwater in the MUD. Most rivers eventually flow into the Yellow River or sodic lakes in sandy land. The groundwater table is shallow, approximately 1–3 m below the ground, especially in the inter-dune regions (Karnieli et al. 2014; Liang and Yang 2016). The annual mean temperature ranges from 6.0 to 8.5 °C, and the mean annual precipitation is approximately 250–400 mm, 60–80% of which falls in summer (Li et al. 2015).

Grassland and desert are the main land use types in the study area. Historically, grassland reclamation has been known as the "fertile land of million hectares", with advanced farming and grazing as early as the Qin and Han Dynasties (Liu et al. 2003). The policy "provide for people with other lands" caused the conversion of naturally vegetated land to cropland in the mid-Qing Dynasty (1644–1911 AD) (Liu et al. 2003). Cropland continued to encroach on grassland until the GTGP was implemented in 1999 (Li et al. 2017). However, the phenomenon of grassland reclamation has been found through field investigations by the author in recent years to have increased significantly after the second stage of the GTGP.

Data and methods

TM images for the 2010 data and OLI images for the 2015 data (nominal resolution of 30 × 30 m) were acquired from https://glovis.usgs.gov/. All images were obtained during the region's growing season. The images were georeferenced and orthorectified by ground control points (GCPs) derived from a 1:100,000 topographic map developed by the Chinese Mapping Agency in the early 1980s. The mean location error after georectification was less than 1 pixel.

An object-based approach was chosen to interpret grassland and farmland information due to the unique feature of the object-based approach that image objects—not individual pixels—become the basic units of analysis, as they

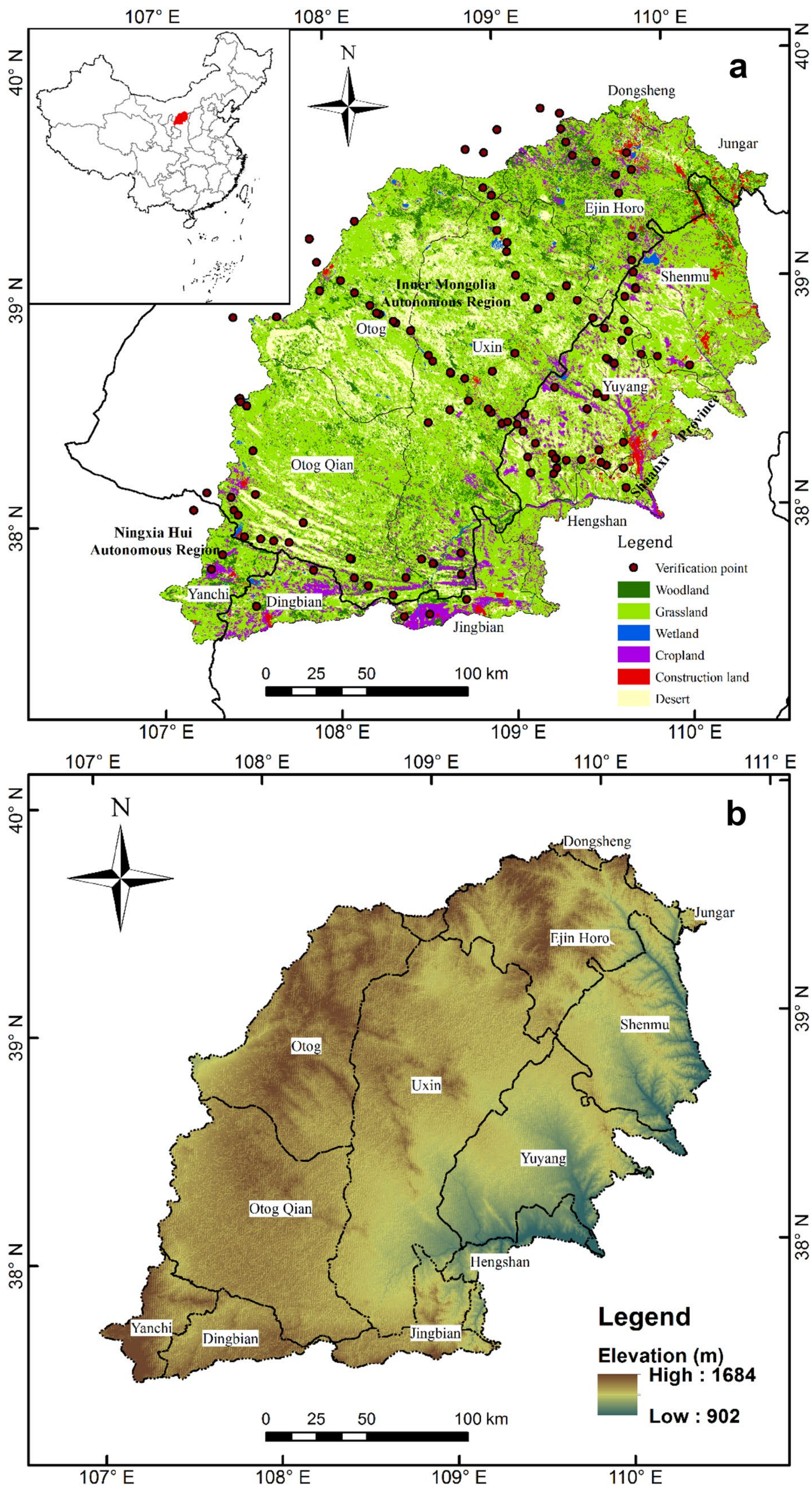

Fig. 1 Overview of the study area. **a** Location, sample sites, and land use (2015) of Mu Us Desert. **b** SRTM DEM map of the study area, original data source from Consortium for Spatial Information (CGIAR-CSI) (http://srtm.csi.cgiar.org/srtmdata/)

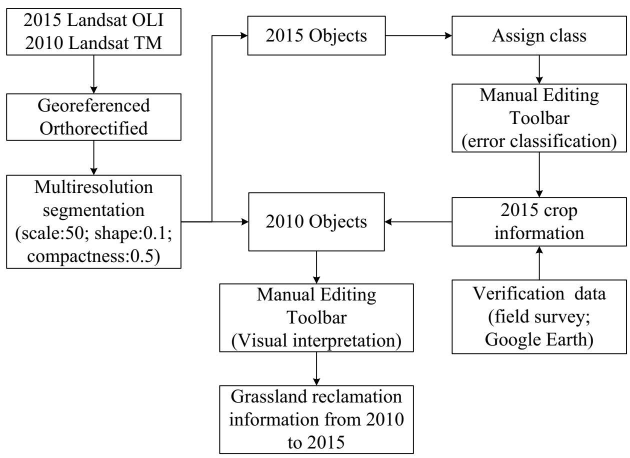

Fig. 2 Scheme of grassland reclamation information extraction using the object-based approach

represent meaningful geographic entities or phenomena at multiple scales (Blaschke 2010; Chen et al. 2018).

The operation process is as follows (Fig. 2). After a trial-and-error method, the meaningful and homogeneous objects in the OLI images for 2015 are segmented using a multiresolution segmentation method, and the parameters of scale, shape, and compactness are 50, 0.1 and 0.5, respectively (Jia et al. 2014), based on the eCognition Developer 8.64 software. Then, using the algorithm "assign class", the cropland is extracted by the ratio vegetation index (RVI) (Jordan 1969), which is set to be greater than 3.0. There are two types of classification errors in the process of classification. One is that a small percentage of high-cover grassland is misclassified as cropland. The other is that newly cultivated land is not classified as cropland because its RVI value is similar to that of bare ground. Therefore, the tool Manual Editing Toolbar was used to reclassify the error classification according to visual interpretation. The cropland information in 2015 is fully extracted. Subsequently, the Landsat TM image from 2010 and the farmland information from 2015 are simultaneously loaded into the eCognition Developer 8.64, and the object information is again assigned by the tool Manual Editing Toolbar. Finally, the verification sample data obtained from the field survey and Google Earth are imported into eCognition. The classification results are assessed through the available Google Earth image sampling points and field survey data. A total of 120 cropland verification points are accurately obtained using a HOLUX GPS M241 in April and June 2017, on which 118 patches are correctly classified. The classification accuracy is 98.33%.

Results and discussion

Spatial distribution of grassland reclamation

Table 1 and Fig. 3 present the profile and geographical patterns of grassland reclamation in the MUD, showing that the trend of conversion from cropland to grassland was reversed dramatically after the end of the second stage of the GTGP. The area of grassland reclamation increased by 411.29 km^2 from 2010 to 2015, accounting for 9.78% of the total cropland area in 2015. The majority of grassland reclamation occurred in the southeastern and southwestern parts of the MUD, and the area of grassland reclamation was relatively rare northwest of the MUD because the moving sand dunes of the MUD were mainly distributed in the northwest, which was unsuitable for tillage (Fig. 1). According to the administrative division (Fig. 1a), the MUD is located at the border of Shaanxi Province, Ningxia Hui Autonomous Region, and the Inner Mongolia Autonomous Region and includes 12 counties. The majority of grassland reclamation was distributed within Inner Mongolia and Shanxi, accounting for 211.37 km^2 and 196.20 km^2, respectively. When analysing at the county scale, grassland reclamation was mainly distributed within the Yuyang District, Otog Qian Banner, and Uxin Banner, accounting for 118.27 km^2, 89.00 km^2, and 82.96 km^2, respectively.

Two patterns of grassland reclamation

According to the field investigation in April and June 2017, we determined that there were two patterns of reclaimed grassland (Fig. 4). One pattern is that herdsmen cultivated pasture or feed corn on their own pasture. The characteristics

Table 1 The area of grassland reclamation in the study region

Province/autonomous region	County/banner	Area (km^2)	Total
Inner Mongolia	Dongsheng	0.98	211.37
	Otog Qian	89.00	
	Otog	5.06	
	Uxin	82.96	
	Ejin Horo	33.22	
	Jungar	0.16	
Shanxi	Dingbian	22.69	196.20
	Hengshan	2.84	
	Jingbian	20.16	
	Shenmu	32.25	
	Yuyang	118.27	
Ningxia	Yanchi	3.72	3.72
Total		411.29	

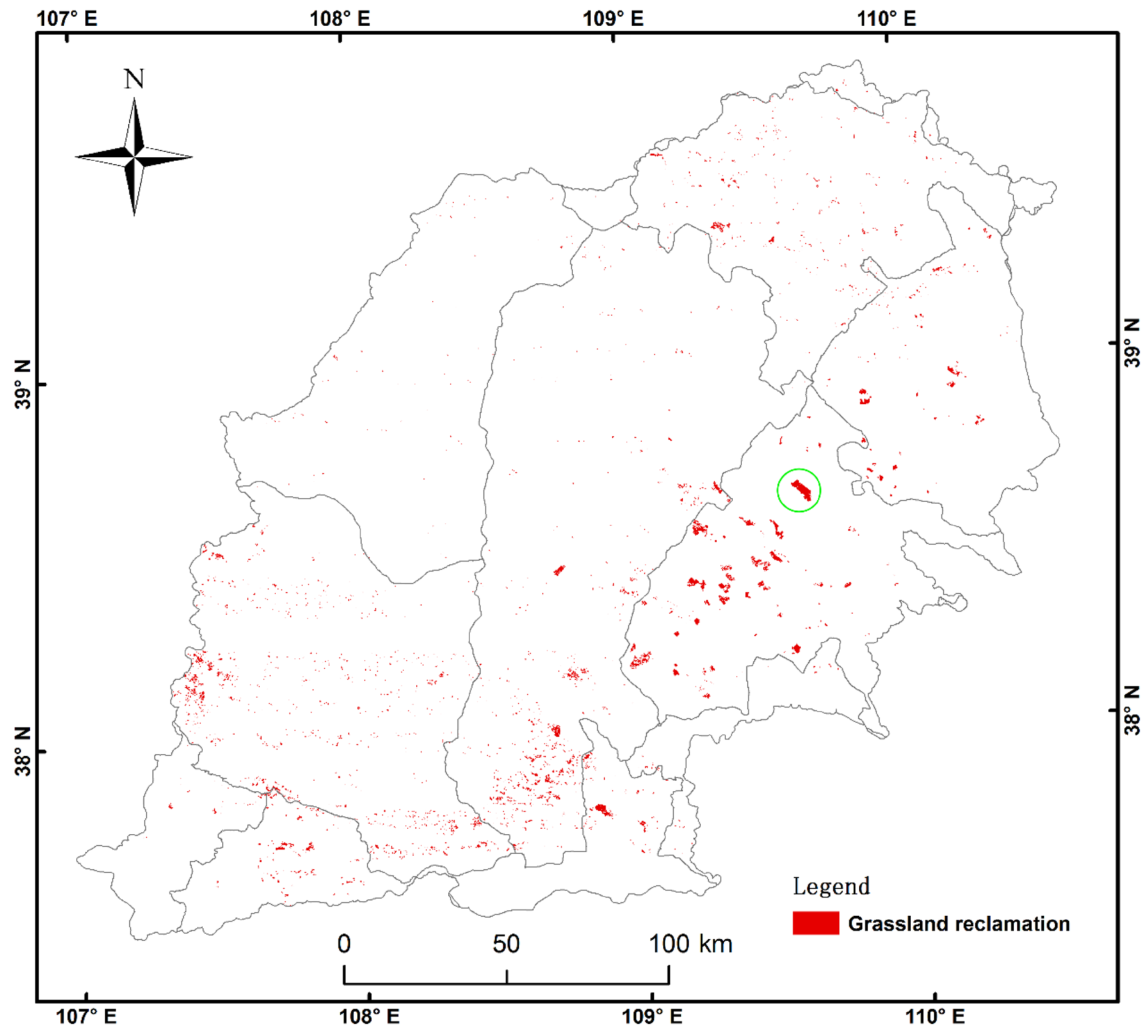

Fig. 3 The grassland reclamation map of the Mu Us Desert from 2010 to 2015. The green circle marks the position of Fig. 5

of this method are small area, self-sufficient, and rough field management and irrigation through pumping groundwater by means of flooding or sprinklers. The management of leaving standing crop residues is carried out after gaining the corn or artificial pastures. This fractured patch of reclaimed land is mainly found in the Inner Mongolia Autonomous Region of the MUD (Fig. 3). The other pattern is that grassland reclamation projects are implemented by enterprises under the direction of local government. The features are large area, maximum interest, normative management (with little residue or field ploughing retained after harvesting potato or corn), and irrigation through pumping groundwater by means of sprinklers. The large patch of reclaimed land mainly appears in the Shanxi Province region of the MUD (Fig. 3). For example, Fig. 5 shows the largest grassland reclamation patches in the MUD, which were implemented by the Shaanxi Provincial Land Engineering Construction Group Co., Ltd., with the Land and Resources in Shaanxi Province (Fig. 5a). Reclamation of the region began in 2010; the area used to be a sand sagebrush (*Artemisia filifolia*) shrub ecosystem (Fig. 5b). By the end of 2015, the area of grassland reclamation was 16.24 km^2 (Fig. 4c, d). Obviously, the second pattern can produce more economic benefits. However, some study results show that wind erosion over ploughed fields was significantly higher than that over stubble corn fields (Sharratt and Collins 2018). Therefore, the second pattern may cause more serious wind erosion than the first pattern.

Negative effects that may be caused by grassland reclamation

Grassland reclamation destroys the topsoil structure and native vegetation, and a large proportion of areas are fallow during the windy spring season (Hoffmann et al. 2011). Consequently, bare and ploughed soils are more susceptible

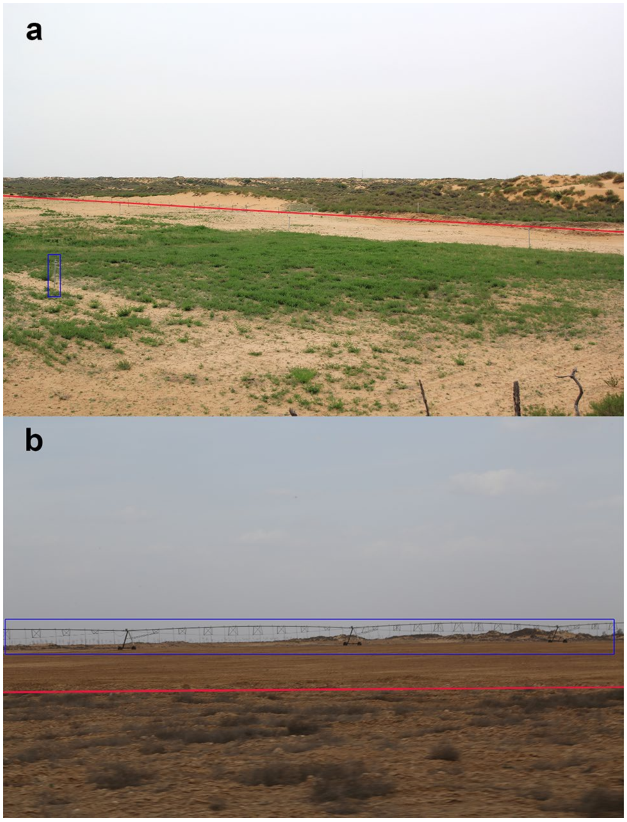

Fig. 4 The two method patterns of grassland reclamation in the MUD. **a** Grassland was reclaimed by herdsmen, and the crop was alfalfa (*Medicago sativa L.*), which was used to make silage; **b** the grassland reclamation project was implemented by enterprises, and the crop was potato (*Solanum tuberosum L.*), which was used to gain income. The blue boxes indicate two different irrigation methods. **a** A permanent pipeline sprinkler irrigation system; **b** a sprinkler system with a travelling pipe. The red lines mark the boundaries between the grassland and cropland

to wind erosion than grassland. Many simulative wind tunnel experiments of cultivated and non-cultivated soil have shown that wind erosion may be accelerated 2–15 times by cultivation in northern China during the windy spring season (Cai and Wang 1999; Dong et al. 1987; Hoffmann et al. 2011; Zhang and Dong 2014). Zhang and Dong (2014) analysed the total sediment transport for five surface types, including cultivated land planted with wheat or oilseed crops, and fixed dunes, with approximately 35% vegetation cover of sand sagebrush in the Yanchi County region of the MUD (Fig. 6). The amount of cultivated land was five times that of the fixed dunes during the entire year. In addition, Du et al. (2018) built a wind erosion model with a high spatio-temporal resolution that was developed and employed to identify the sand/dust emissions in areas within northern China from 2001 to 2014. Simulations show that the proportions of dust emissions were related to the fractions of areas of different land cover types and that the total dust emission fraction of cropland first displayed a decreasing trend from 2000 to 2008, followed by a rapidly increasing trend from 2008 to 2013 (Du et al. 2018) (Fig. 7). The results also indicated that an increase in cropland leads to an increase in sand/dust emissions in the MUD. Ultimately, wind erosion may decrease agricultural productivity (Buerkert and Lamers, 1999) and trigger desertification (Zhao et al. 2006) with the selective removal of fine particles, nutrients and organic matter, and the accumulation of coarse mineral grains (Hoffmann et al. 2011; Houyou et al. 2016; Li et al. 2005; Wiesmeier et al. 2015; Zhang and Dong 2014). Previous studies (Su et al. 2004; Zhang et al. 2013; Zhang and Dong, 2014) have suggested large amounts of silt and clay (diameter < 0.05 mm) losses by wind erosion, and the remaining particles tend to be coarse, which is similar to those of shifted sand in the near-surface layers in the grassland reclamation areas. Meanwhile, soil organic carbon (SOC) and nitrogen (N) were lost with the removal of silt and clay under the cultivation of sandy grasslands and subsequent short-term tillage practices (Su et al. 2004; Zhang et al. 2013). According to the studies of Wu et al. (2003) and Xie et al. (2007), Wang et al. (2011) determined that the conversion of freely grazed grassland to cropland led to an approximate 36% SOC loss in surface soils (0–20 cm) in grassland in Northern China. Su et al. (2004) and He et al. (2012) studied the N storage of reclaimed lands at different times in the Horqin Sandy Land and at the Inner Mongolia Grassland Ecosystem Research Station (43°33′N, 116°40′E), respectively. These results showed that cultivation significantly reduced N storage in the 0–15 cm ploughed layer.

Strong motivations and effective measures to prevent grassland erosion

Strategies to reduce wind erosion on reclaimed grassland in arid and semi-arid grasslands have been carried out (Hoffmann et al. 2011), such as leaving standing crop residues (Hagen 1996; Wang et al. 2002), reducing tillage intensity (Mendez and Buschiazzo 2010), using several alternative cultivation systems (Li et al. 2002), and applying ridge tillage (Liu et al. 2006). However, as the authors were investigating grassland reclamation in the MUD, the first two strategies were unsuccessful in the study area because the soil surface layers had to be disturbed when digging the potatoes, which destroyed the non-tillage systems and crop residues. Generally, it was learnt through interviews with local farmers that two alternative rotations, mainly using potatoes and maize, were established to reduce wind erosion in the study area. Ridge tillage is worth using as an alternative practice for reducing wind erosion during the fallow period and can decrease wind erosion by 20–60% (Liu et al. 2006). However, regardless

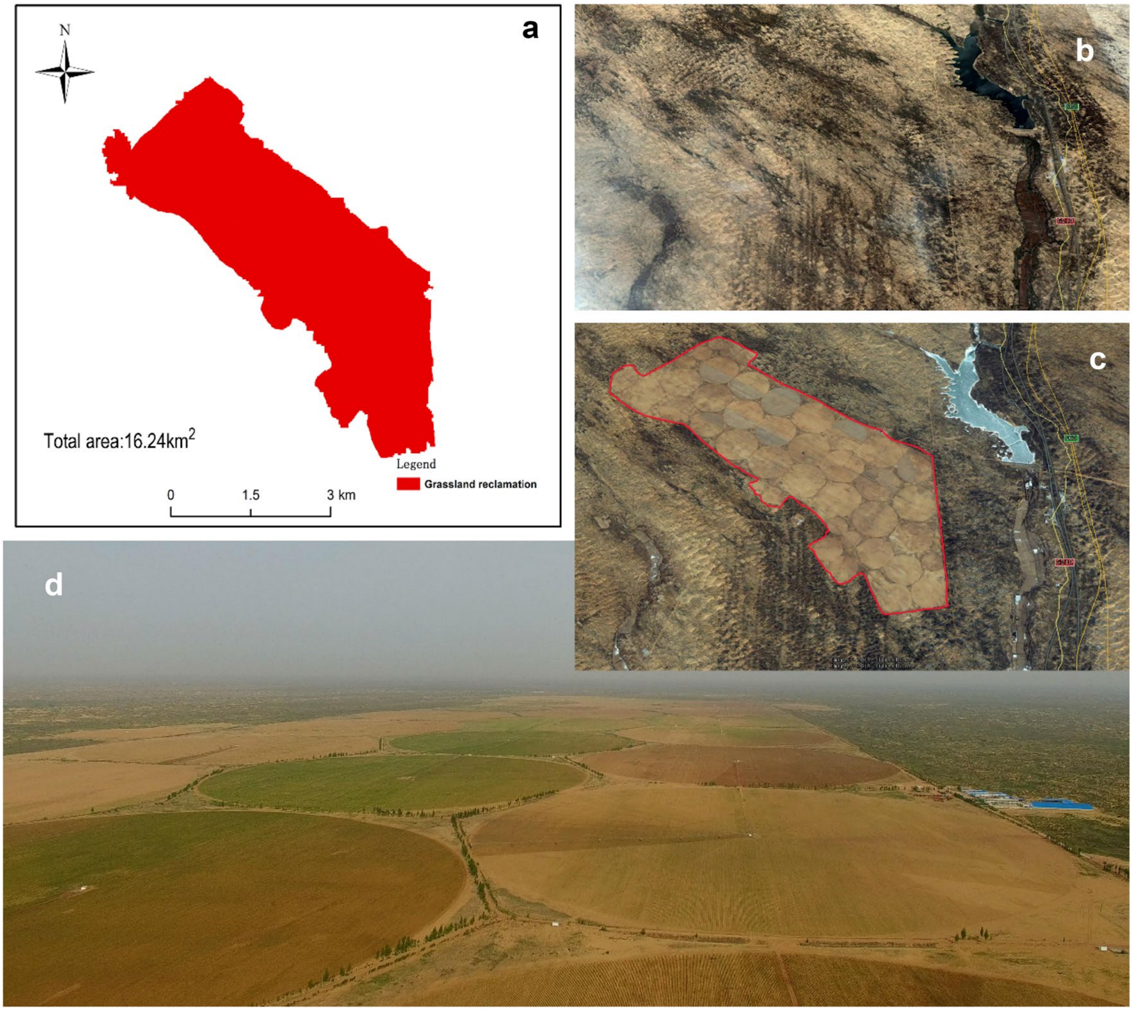

Fig. 5 The grassland reclamation region in the study. **a** Area of grassland reclamation in Mengjiawan Town, Yulin City, Shanxi Province (longitude: 109°38′15″; latitude: 109°38′15″; the green circle in Fig. 1.). **b** Image from Google Earth dated September 25, 2009. **c** Image from Google Earth dated January 31, 2016. **d** Photograph taken by the DJI Phantom 3 UAV on June 9, 2017

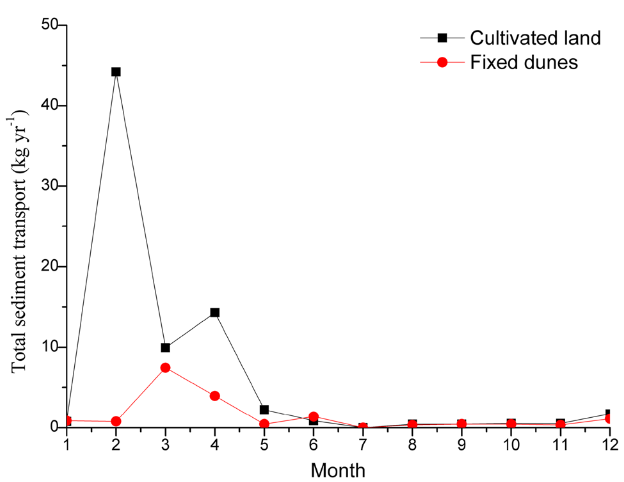

Fig. 6 Total sediment transport in different months above cultivated land and fixed dunes in 2006. Data are from Zhang and Dong (2014)

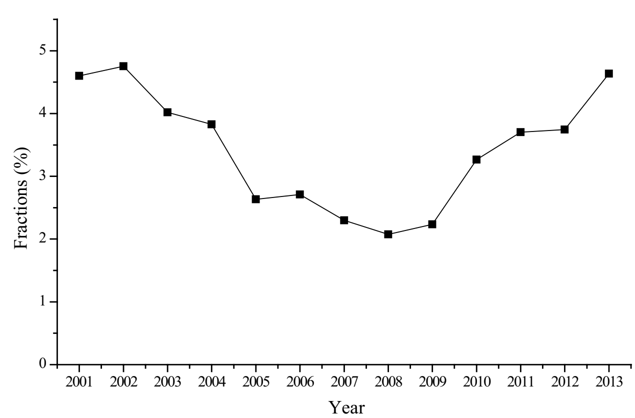

Fig. 7 Fractions of dust emissions from cropland between 2001 and 2013. Data are from Du et al. (2018)

of the kind of protective measure taken, reclaimed grasslands cannot be restored to their original condition.

Superficially, grassland reclamation is related to national policy and the prompting of short-term economic benefits. The main reason is that the government regards large sandy lands and grasslands as reserve resources for cultivated land, and there are even reports that the MUD would be transformed into a new base for regional commercial grain production. The sandy soil area, with less than 400 mm of precipitation, is not suitable for large-scale grassland reclamation north of the Great Wall because of fragile soil conditions and the strong wind environment. Therefore, the study area should be classified as a high-risk ecological region for dry farming, and tillage should be prohibited (Hoffmann et al. 2011).

Conclusions

The conversion from grassland to cropland was effectively curbed with the implementation of the Grain-to-Green Program in northern China from 1999 to 2010, and soil properties were significantly improved in a short time (Zhang et al. 2013). However, the phenomenon of grassland reclamation has significantly increased since 2010. The latest grassland reclamation trend is worthy of close attention in the Mu Us Desert and even the whole grassland region of northern China.

In this paper, we use an object-based approach to detect and evaluate the latest trend in the conversion from grassland to cropland. The results show that the area of grassland reclamation increased by 411.29 km^2 from 2010 to 2015 and was mainly distributed in the southeastern and southwestern parts of the Mu Us Desert, accounting for 9.78% of the total cropland area in 2015. Interviews with local farmers revealed two ways to reclaim grassland, including herdsmen cultivating grasslands on their own pastures and grassland reclamation projects implemented by enterprises under the direction of local governments. Exposed cultivated land is more susceptible to wind erosion, which eventually leads to decreased agricultural productivity and desertification with the selective removal of fine particles, nutrients, and organic matter and the accumulation of coarse mineral grains. Appropriate tillage strategies should be selected according to local water and soil conditions and crop types.

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References

Assessment ME (2005) Ecosystems and human well-being: current state and trends. Island Press, Washington, DC

Blaschke T (2010) Object based image analysis for remote sensing. ISPRS J Photogramm Remote Sens 65:2–16

Buerkert A, Lamers JPA (1999) Soil erosion and deposition effects on surface characteristics and pearl millet growth in the West African Sahel. Plant Soil 215:239–253

Bureau CS (2016) China statistical yearbook. China Statistical Bureau, Beijing

Cai D, Wang X, (1999) Conservation tillage systems for spring maize in the semi-humid to arid areas of China. In: Proceedings sustaining the global farm-selected papers from the 10th international soil conservation organization meeting, Purdue University, pp 366–370

Carbutt C, Henwood WD, Gilfedder LA (2017) Global plight of native temperate grasslands: going, going, gone? Biodivers Conserv 26(12):2911–2932

Chen G, Weng QH, Hay GJ, He YN (2018) Geographic object-based image analysis (GEOBIA): emerging trends and future opportunities. GIScience Remote Sens 55(2):159–182

Dong GR, Li CZ, Jin J (1987) Some results of simulated tests of soil erosion by wind in wind tunnel. Chin Sci Bull 32:1703–1709

Du HQ, Wang T, Xue X, Li S (2018) Modelling of sand/dust emission in Northern China from 2001 to 2014. Geoderma 330:162–176

Gavier-Pizarro GI, Calamari NC, Thompson JJ, Canavelli SB, Solari LM, Decarre J, Goijman AP, Suarez RP, Bernardos JN, Zaccagnini ME (2012) Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density. Agr Ecosyst Environ 154:44–55

Hagen L (1996) Crop residue effects on aerodynamic processes and wind erosion. Theoret Appl Climatol 54:39–46

He N, Zhang Y, Dai J, Han X, Baoyin T, Yu G (2012) Land-use impact on soil carbon and nitrogen sequestration in typical steppe ecosystems, Inner Mongolia. J Geog Sci 22:859–873

Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. Ecol Lett 8:23–29

Hoffmann C, Funk R, Reiche M, Li Y (2011) Assessment of extreme wind erosion and its impacts in Inner Mongolia, China. Aeol Res 3:343–351

Houyou Z, Bielders CL, Benhorma HA, Dellal A, Boutemdjet A (2016) Evidence of strong land degradation by wind erosion as a result of rainfed cropping in the Algerian steppe: a case study at Laghouat. Land Degrad Dev 27:1788–1796

Jia M, Wang Z, Li L, Song K, Ren C, Liu B, Mao D (2014) Mapping China's mangroves based on an object-oriented classification of Landsat imagery. Wetlands 34(2):277–283

Jordan CF (1969) Derivation of leaf-area index from quality of light on the forest floor. Ecology 50:663–666

Karnieli A, Qin ZH, Wu B, Panov N, Yan F (2014) Spatio-temporal dynamics of land-use and land-cover in the Mu Us Sandy Land, China, using the change vector analysis technique. Remote Sens 6(10):9316–9339

Li FR, Gao CY, Zhao HL, Li XY (2002) Soil conservation effectiveness and energy efficiency of alternative rotations and continuous wheat cropping in the Loess Plateau of northwest China. Agr Ecosyst Environ 91:101–111

Li FR, Kang LF, Zhang H, Zhao LY, Shirato Y, Taniyama I (2005) Changes in intensity of wind erosion at different stages of degradation development in grasslands of Inner Mongolia, China. J Arid Environ 62:567–585

Li N, Yan CZ, Xie JL (2015) Remote sensing monitoring recent rapid increase of coal mining activity of an important energy base in northern China, a case study of Mu Us Sandy Land. Resour Conserv Recycl 94:129–135

Li S, Wang T, Yan CZ (2017) Assessing the role of policies on land-use/cover change from 1965 to 2015 in the Mu Us Sandy Land, Northern China. Sustainability 9:1164

Liang P, Yang XP (2016) Landscape spatial patterns in the Maowusu (Mu Us) Sandy Land, northern China and their impact factors. CATENA 145:321–333

Liu Y, Gao J, Yang Y (2003) A holistic approach towards assessment of severity of land degradation along the Great Wall in Northern Shaanxi Province, China. Environ Monit Assess 82:187–202

Liu MX, Wang JA, Yan P, Liu LY, Ge YQ, Li XY, Hu X, Song Y, Wang L (2006) Wind tunnel simulation of ridge-tillage effects on soil erosion from cropland. Soil Tillage Res 90:242–249

Liu W, Cao SK, Xi HY, Feng Q (2010) Land use history and status of land desertification in the Heihe River basin. Nat Hazards 53:273–290

Liu J, Kuang W, Zhang Z, Xu X, Qin Y, Ning J, Zhou W, Zhang S, Li R, Yan C, Wu S, Shi X, Jiang N, Yu D, Pan X, Chi W (2014) Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. J Geog Sci 24:195–210

Maeda EE, Pellikka PK, Siljander M, Clark BJ (2010) Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya. Geomorphology 123:279–289

Mendez MJ, Buschiazzo DE (2010) Wind erosion risk in agricultural soils under different tillage systems in the semiarid Pampas of Argentina. Soil and Tillage Res 106:311–316

Ning J, Liu JY, Kuang WH, Xu XL, Zhang SW, Yan CZ, Li RD, Wu SX, Du GM, Du Hu YF, Chi WF, Pan T, Ning J (2018) Spatiotemporal patterns and characteristics of land-use change in China during 2010–2015. J Geog Sci 28(5):547–562

Ouyang ZY, Zheng H, Xiao Y, Polasky S, Liu JG, Xu WH, Wang Q, Zhang L, Xiao Y, Rao EM, Jiang L, Lu F, Wang XK, Yang GB, Gong SH, Wu BF, Zeng Y, Yang W, Daily GC (2016) Improvements in ecosystem services from investments in natural capital. Science 352:1455–1459

Qi Y, Dong Y, Peng Q, Xiao S, He Y, Liu X, Sun L, Jia J, Yang Z (2012) Effects of a conversion from grassland to cropland on the different soil organic carbon fractions in Inner Mongolia, China. J Geog Sci 22:315–328

Reiche M, Funk R, Hoffmann C, Zhang ZD, Sommer M (2015) Vertical dust concentration measurements within the boundary layer to assess regional source–sink relations of dust in semi-arid grasslands of Inner Mongolia, China. Environ Earth Sci 73(1):163–174

Sharratt BS, Collins HP (2018) Wind Erosion potential influenced by tillage in an irrigated potato–sweet corn rotation in the Columbia Basin. Agron J 110(3):842–849

Stephens SE, Walker JA, Blunck DR, Jayaraman A, Naugle DE, Ringelman JK, Smith AJ (2008) Predicting risk of habitat conversion in native temperate grasslands. Conserv Biol 22:1320–1330

Su YZ, Zhao HL, Zhang TH, Zhao XY (2004) Soil properties following cultivation and non-grazing of a semi-arid sandy grassland in northern China. Soil Tillage Res 75:27–36

Suttie, JM, Reynolds SG, Batello C (2005) Grasslands of the World. Food and Agriculture Org, Rome

Wang ED, Harman WL, Williams JR, Xu C (2002) Simulated effects of crop rotations and residue management on wind erosion in Wuchuan, west-central Inner Mongolia, China. J Environ Qual 31:1240–1247

Wang SP, Wilkes A, Zhang ZC, Chang XF, Lang R, Wang YF, Niu HS (2011) Management and land use change effects on soil carbon in northern China's grasslands: a synthesis. Agr Ecosyst Environ 142(3–4):329–340

Wang T, Yan CZ, Song X, Xie JL (2012) Monitoring recent trends in the area of aeolian desertified land using Landsat images in China's Xinjiang region. ISPRS J Photogramm Remote Sens 68:184–190

White RP, Murray S, Rohweder M, Prince SD, Thompson KM (2000) Grassland ecosystems. World Resources Institute, Washington, DC

Wiesmeier M, Munro S, Barthold F, Steffens M, Schad P, Kogel-Knabner I (2015) Carbon storage capacity of semi-arid grassland soils and sequestration potentials in northern China. Glob Chang Biol 21:3836–3845

Wright CK, Wimberly MC (2013) Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc Natl Acad Sci 110:4134–4139

Wu B, Ci LJ (2002) Landscape change and desertification development in the Mu Us Sandland, Northern China. J Arid Environ 50(3):429–444

Wu H, Guo Z, Peng C (2003) Land use induced changes of organic carbon storage in soils of China. Glob Chang Biol 9(3):305–315

Xie ZB, Zhu JG, Liu G, Cadisch G, Hasegawa T, Chen CM, Sun HF, Tang HY, Zeng Q (2007) Soil organic carbon stocks in China and changes from 1980s to 2000s. Glob Change Biol 13(9):1989–2007

Yan P, Dong ZB, Dong GR, Zhang XB, Zhang YY (2001) Preliminary results of using137Cs to study wind erosion in the Qinghai-Tibet Plateau. J Arid Environ 47:443–452

Yan F, Wu B, Wang YJ (2015) Estimating spatiotemporal patterns of aboveground biomass using Landsat TM and MODIS images in the Mu Us Sandy Land, China. Agric For Meteorol 200:119–128

Zhang ZC, Dong ZB (2014) Characteristics of aeolian sediment transport over different land surfaces in northern China. Soil Tillage Res 143:106–115

Zhang ZH, Li XY, Jiang ZY, Peng HY, Li L, Zhao GQ (2013) Changes in some soil properties induced by re-conversion of cropland into grassland in the semiarid steppe zone of Inner Mongolia, China. Plant Soil 373:89–106

Zhao HL, Zhou RL, Zhang TH, Zhao XY (2006) Effects of desertification on soil and crop growth properties in Horqin sandy cropland of Inner Mongolia, north China. Soil Tillage Res 87:175–185

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